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State of California
The Resources Agency

DEPARTMENT OF FISH AND GAME

REPORT TO THE FISH AND GAME COMMISSION:

A STATUS REVIEW OF THE DELTA SMELT (HYPOMESUS TRANSPACIFICUS) IN CALIFORNIA

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EXECUTIVE SUMMARY

This report was prepared in response to a petition received by the Fish and Game Commission from Dr. Peter B. Moyle of the University of California at Davis to list the Delta smelt (Hypomesus transpacificus) as an Endangered Species under the authority of the California Endangered Species Act (Fish and Game Code Sections 2050 et seq.).

On August 23, 1989, pursuant to the Section 2074.2 of the California Endangered Species Act (CESA), the Commission determined that the petition contained sufficient information to indicate that the petitioned action may be warranted. Pursuant to Section 2074.6 of CESA, the Department undertook a review of this petition. Based on the best scientific information available on the Delta smelt, the Department has evaluated whether, in fact, the petitioned action should be taken. Information and comments on the petitioned action and the Delta

1/ Prepared August 1990.

smelt were solicited from interested parties, management agencies, and the scientific community.

This report presents the results of our review and analysis.

Findings

The Delta smelt is a small fish endemic to the Sacramento-San Joaquin Estuary. Delta smelt are euryhaline and much of the year are typically most abundant in the entrapment zone, where incoming saltwater and outflowing freshwater mix. This species feeds exclusively on zooplankton, spawns in freshwater, and usually only lives for one year.

Information from six different data sets all indicate that the population of Delta smelt has declined. The best measures, based on the summer townet and fall midwater trawl surveys, indicate that abundance of this species has been consistently low since 1983. Based on the midwater trawl survey, the average population since 1983 has been only about one-fifth of the average population level from 1967 to 1982, and one-tenth of the peak level in 1980.

Conclusions

Although the petitioner requested that the species be listed as endangered, the Department finds that the Delta smelt should be listed as a threatened species, based on Section 670.1(b) of Title 14 of the California Code of Regulations and Section 2072.3 of the Fish and Game Code. The Department's findings are based on the following:

1. The recent decline in the copepod, Eurytemora affinis, a major diet component of the Delta smelt, must be considered as a potential threat to the smelt's recovery unless other food resources compensate or this copepod recovers to its former abundance.

2. Although spawning stock abundance may not have been an important factor in Delta smelt year class success in the past, present or future low stock levels may inhibit the potential for population recovery. The relatively low fecundity of this species and its planktonic larvae, which undoubtedly incur high rates of mortality, indicate that year class success of the Delta smelt must depend on reproduction by fairly large numbers of fish.

3. The relationship between Delta smelt abundance and water diversions is not clear. Delta smelt are ecologically similar to young striped bass which have been severely impacted by water diversions. Whether or not water diversions are directly responsible for the Delta smelt

population decline, their drain on the population may be a significant factor inhibiting recovery.

4. Although there is no direct evidence of Delta smelt suffering direct mortality or stress from toxic substances, such substances cannot be eliminated as having adverse effects on the population.

5. There is no evidence that Delta outflow has had major effects on Delta smelt abundance.

6. No research has been done to determine if the wagasaki, a closely related species introduced into several reservoirs in the Delta drainage, hybridizes with or competes directly with the Delta smelt.

7. A number of exotic fish and invertebrate species have been introduced into the Sacramento-San Joaquin Estuary. Although none of these species can be directly linked to the decline in Delta smelt, their presence may inhibit the smelt's recovery.

8. Diseases and parasites of Delta smelt have never been studied; thus, there is no evidence concerning their role in the population decline. Should they be important, they

could prevent the recovery of Delta smelt from current low population levels.

9. Although competition and predation cannot be ruled out as threats to Delta smelt, the available evidence suggest that they are not a major threat. In fact, several potential competitors or predators also show signs of population erosion approximately coinciding with or preceding the decline of Delta smelt.

10. The Delta smelt population trend, certain life history attributes, and environmental threats tend to support listing. The scientific information is insufficient, however, to determine whether the population is low enough that it is in imminent danger of extinction. This is a complicated scientific determination, and no study which might be implemented will provide a conclusive answer in the next few years. Meanwhile, the population might become extinct. The most prudent action, therefore, is to list the Delta smelt as a threatened species.

Recommendations

Listing:

1. The Commission should find that the Delta smelt is a threatened species.

2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the Delta smelt (Hypomesus transpacificus) to its list of Threatened and Endangered Species.

Management and recovery objectives:

1. Improve species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta. Such actions could reduce present entrainment losses to these major diversions.

2. Modify pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when delta smelt are most abundant.

3. Increase spring and summer delta outflows to maintain the entrapment zone and major delta smelt nursery in the Suisun

Bay region where food supplies are greater that in the Delta and exposure to diversions is minimal.

4. Support regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species. S 2244 and HR 4214 currently being considered by the U.S. Congress would create such regulations.

5. Evaluate losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.

6. Remove water project diversions from the Delta. Moving the diversion intakes to the Sacramento River upstream from the major nursery area would do this and also provide benefits to other species which formerly made more use of the Delta.

7. Consider developing pond culture techniques for the purpose of creating "refuge" populations.

<u>Public Responses</u>

During the twelve month review period, the Department contacted a number of affected and interested parties, invited comment on the petition and our draft status review, and requested any additional scientific information that may be available. A copy of the Public Notice and a list of parties contacted are contained in Appendix A. A summary of comments on the draft status review is in Appendix B. Scientific comments will be addressed as part of the regulatory proceedings should the Commission find that the petition warrants action.

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INTRODUCTION

Petition History

On June 13, 1989, the Fish and Game Commission (Commission) received a petition from Dr. Peter B. Moyle of the University of California at Davis, requesting State listing of the Delta smelt (*Hypomesus transpacificus*) as an Endangered Species. The Department of Fish and Game (Department) reviewed the petition and recommended to the Commission that they accept it as complete pursuant to Sections 2072.3 and 2073.5 in the California Endangered Species Act (Fish and Game Code Sections 2050 et seq.) and that the petitioned action may be warranted. On August 29, 1989, the Commission accepted the Department's recommendation and designated the Delta smelt as a Candidate Species as provided for in Section 2074.2 of the California Endangered Species Act (CESA). That action initiated a twelve-month review period,

1/ Prepared August 1990

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pursuant to Section 2074.6 of CESA, within which the Department must review the best scientific information available on the Delta smelt and provide a written report to the Commission indicating whether the petition is warranted.

Department Review

This report contains the results of the Department's review, and a recommendation to the Commission, based on the best scientific information available, whether or not the petitioned action is warranted. It also identifies the habitat that may be essential to the continued existence of the species and suggests management activities and other recommendations for the recovery of the Delta smelt.

During the twelve month review period, the Department contacted affected and interested parties, invited comment on the petition and our draft status review, and requested any additional scientific information that may be available, as required under Section 2074.4, Fish and Game Code. A copy of the Public Notice and a list of parties contacted are contained in Appendix A. A summary of comments on the draft status review is in Appendix B. Scientific comments will be addressed as part of the regulatory proceedings should the Commission find that the petition warrants action.

LIFE HISTORY

Description

The Delta smelt is a small, slender-bodied fish, with a typical adult size of 55-70 mm (standard length), although some may reach 130 mm. This fish has a small, flexible mouth with a maxilla (upper jaw bone) which does not extend past the middle of the eye. When pressed against the body, the pectoral fins reach less than two-thirds of the way to the pelvic fin bases. The upper and lower jaws contain small, pointed teeth. Live Delta smelt have a steely blue sheen on the sides and appear to be almost translucent (Moyle 1976). Delta smelt, like other members of the family Osmeridae, have an adipose fin. Additional, more detailed descriptive information can be found in Moyle (1976).

Taxonomy

The confusing taxonomy of this species is described in Moyle (1976). The Delta smelt was once thought to be a population of the widely distributed pond smelt, *Hypomesus olidus*. The two were recognized as distinct species by Hamada (1961), who renamed the Delta smelt _H. sakhalinus_ and retained the name _H. olidus_ for pond smelt. It was later determined, however, that _H. olidus_ does not occur in California waters, and McAllister (1963) redescribed the Delta smelt as _H. transpacificus_, with Japanese and California subspecies, _H. t. nipponensis_ and _H. t. transpacificus_, respectively. Subsequent work has shown that these two subspecies should be recognized as species, with the Delta smelt being _H. transpacificus_ and the Japanese fish (wagasaki) being _H. nipponensis_ (Moyle 1980).

Range

The delta smelt occurs only in the Sacramento-San Joaquin Estuary.

Diet

Delta smelt feed exclusively on zooplankton. Department biologists examined gut contents of two 8 mm and 9 mm delta smelt larvae captured in 1988 which had eaten harpacticoid copepods, calanoid copepods and copepod nauplii. The diet of 20-mm to 40-mm-long juveniles collected by the Department in 1974 was comprised mainly of calanoid copepods, especially _Eurytemora affinis_, which was the dominant food (Table 1). There was no evidence of a major shift in diet as the smelt grew larger.

Table 1. *Items in the diet of delta smelt collected from the townet survey at station 519 on June 28 and July 13, 1974.*

Length group (mm)	Total fish	Number w/food	Cyclopidae	*Eurytemora*	*Diaptomus*	Harpacticoid copepod	*Neomysis*	Other copepod
20-24	2	1		2				
25-29	18	17		117	1	1		8
30-34	18	17	2	585			1	45
35-39	12	12	0	220			1	34

Moyle and Herbold (MS) examined the diet of delta smelt from 15 samples collected at various times from 1972 to 1974 and for two fall samples collected in 1988. They found copepods to be the dominant diet item and the opossum shrimp, Neomysis mercedis, was second. E. affinis was the primary copepod in stomachs in the 1972-1974 sample. Pseudodiaptomus forbesi, an accidentally introduced exotic copepod which first became abundant in spring 1988, was an important diet item that year. The amphipod, Corophium sp, and two cladocerans, Bosmina sp. and Daphnia sp., were also eaten.

Reproduction and Growth

Spawning occurs in freshwater at temperatures of 7-15°C (Wang 1986). It generally takes place from February through June, probably mostly in the dead end sloughs (Radtke 1966) and shallow edge-waters of the channels of the Delta (Wang 1986) and the Sacramento River. Catches of young delta smelt, 20-30 mm in length, during salmon seine surveys in May document the occurrence of spawning in the Sacramento River (Table 2). Some spawning has also been recorded in Montezuma Slough, near Suisun Bay (Radtke 1966, Wang 1986). Each female deposits from 1400 to 2900 demersal, adhesive eggs on substrates such as rock, gravel, tree roots, and submerged vegetation (Moyle 1976; Wang 1986; Moyle and Herbold, MS). Eggs probably hatch in 12-14 days if

Table 2. Catch per haul (C/H) and mean fork length in millimeters (FL) of delta smelt at Sacramento River beach seine sites in 1978. Number of seine hauls in parentheses.

Site	Feb C/H		Feb FL	Mar C/H		Mar FL	Apr C/H		Apr FL	May C/H		May FL	June C/H		June FL
Isleton		(0)		1.3	(3)	69	0.0	(1)		2.0	(1)	22		(0)	
Ryde		(0)		1.0	(2)	46	1.2	(4)	75	13.3	(3)	24		(0)	
Clarksburg		(0)		0.0	(5)		5.8	(4)	68	70.7	(3)	26		(0)	
Garcia Bend	0.0	(2)		1.5	(4)	66	0.2	(4)	71	5.7	(3)	24		(0)	
Mouth American River	0.0	(2)		0.0	(5)		0.0	(3)		0.2	(4)	68	0.0	(1)	

developmental rates are similar to those of the closely related wagasaki (Wales 1962).

After hatching, larvae float to the surface (Moyle 1976) and many are carried by currents downstream to the mixing (entrapment) zone (see "Distribution and Essential Habitat"). Growth is rapid; juvenile smelt are 40-50 mm long by early August (Erkkila et al. 1950, Ganssle 1966, Radtke 1966). Adult lengths are reached by the time they are 6 to 9 months old (Moyle 1976). Thereafter, they only grow another 3-9 mm, presumably because most energy is being channeled into the development of gonads (Erkkila et al. 1950, Radtke 1966).

Most Delta smelt die after spawning, although a few may survive to be 2 years old. There is evidence that almost total reproductive failure can occur in some years. Erkkila et al. (1950), for example, collected no young-of-the-year smelt in their second year of sampling, although their previous year's data suggested that large numbers should have been present.

DISTRIBUTION AND ESSENTIAL HABITAT

Delta smelt are euryhaline, and much of the year are typically most abundant in the entrapment zone (Arthur and Ball 1979) where incoming saltwater and outflowing freshwater mix (Tables 3, 4, and 5). This mixing effect allows organisms which swim poorly, such as zooplankton and larval fish, to remain in the entrapment zone rather than being flushed out to sea. Hence, delta smelt spend their life from the larval period to pre-spawning adulthood in the Delta and brackish areas downstream, particularly the Suisun Bay region (Ganssle 1966, Radtke 1966, Moyle and Herbold 1989). Surveys by the San Francisco Bay - Outflow Study, which has sampled fish in the Estuary from San Francisco Bay to the western Delta since 1980, indicate that delta smelt thin out in San Pablo Bay and are virtually non-existent in San Francisco Bay (Table 3).

Summer townet and fall midwater trawl surveys (pages 17 to 23), conducted by the Department for young striped bass (Morone saxatilis), indicate delta smelt are most frequently caught where specific conductance ranges from 500 to 8000 microsiemens (Tables 3, 4 and 5). These surveys also demonstrate that the geographical distribution of delta smelt during summer and fall is strongly influenced by delta outflow. As flows increase and saltwater is repelled, more of the population occurs in Suisun and San Pablo bays and less occurs in the Delta (Figures 1 and 2).

Table 3. San Francisco Bay - Outflow study catch of delta smelt by month and area, 1980-1988. Number of sampling sites in parentheses.

Area	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
San Francisco Bay (16)	0	0	0	0	0	0	0	0	0	0	0	0	0
San Pablo Bay (8)	4	5	29	1	0	1	0	0	0	54	0	1	95
Carquinez Strait and Western Suisun Bay (6)	61	46	86	37	5	55	70	94	71	36	9	38	608
Eastern Suisun Bay (3)	18	24	15	10	5	8	16	37	54	68	40	12	307
Western Delta (2)	30	13	15	5	2	20	12	23	55	12	33	32	252
Total	113	88	145	53	12	84	98	154	180	170	82	83	1262

Table 4. Summer townet survey catch frequencies for delta smelt by specific conductance (EC) ranges, 1969-1988. 1/

Numbers of smelt per catch

EC (microsiemens)	0	1-4	5-9	10-14	15-19	20-49	50-99	>100	Total Samples	Number Catches >0	Percent with smelt
No Data	9	4	3	1	0	1	1	0	19	10	52.6
1-499	541	170	52	17	10	36	16	14	856	315	36.8
500-999	105	51	13	16	7	13	14	10	229	124	54.1
1000-1999	38	31	15	10	8	17	9	10	138	100	72.4
2000-3999	34	41	15	11	8	22	9	8	148	114	77.0
4000-5999	31	30	11	6	4	6	8	8	104	73	70.0
6000-7999	22	21	9	7	3	11	5	1	79	57	72.1
>8000	338	96	32	14	7	17	14	3	521	183	35.1
Total	1118	444	150	82	47	123	76	54	2094	976	46.6

1/ EC was not measured prior to 1969 even though the survey started in 1959.

Table 5. Fall midwater trawl catch frequencies for delta smelt by specific conductance (EC) ranges, 1967-1988.

Numbers of smelt per catch

EC (microsiemens)	0	1-4	5-9	10-14	15-19	20-49	>50	Total Samples	Number Catches >0	Percent catch with smelt
No Data	9	0	0	0	0	0	0	9	0	0
1-499	1756	604	103	30	16	27	4	2540	784	30.8
500-999	311	137	35	21	7	12	5	528	217	41.1
1000-1999	224	128	43	18	10	18	2	443	219	49.4
2000-3999	269	141	44	30	9	14	5	512	243	47.4
4000-5999	244	97	45	9	10	12	1	418	174	46.1
6000-7999	202	67	23	10	5	9	1	317	115	36.3
>8000	4547	173	24	9	9	11	4	4777	230	4.8
Total	7562	1347	317	127	66	103	22	9544	1982	20.7

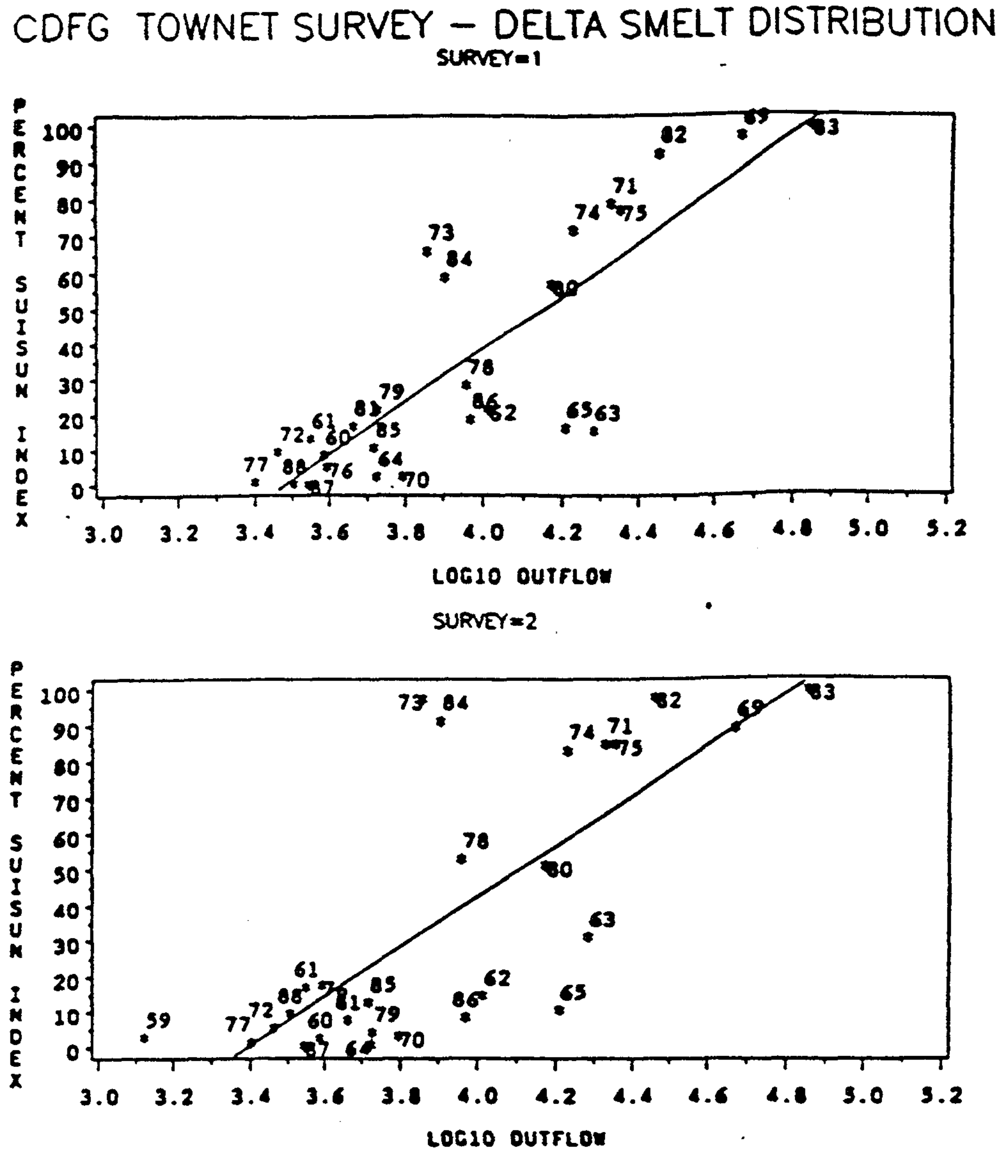

Figure 1. Relationship between the portion of the delta smelt population occurring west of the delta and log delta outflow during the survey period. Data are from the summer townet survey. For arcsine transformed percentages, R^2= 0.74 for survey 1 and R^2= 0.55 for survey 2.

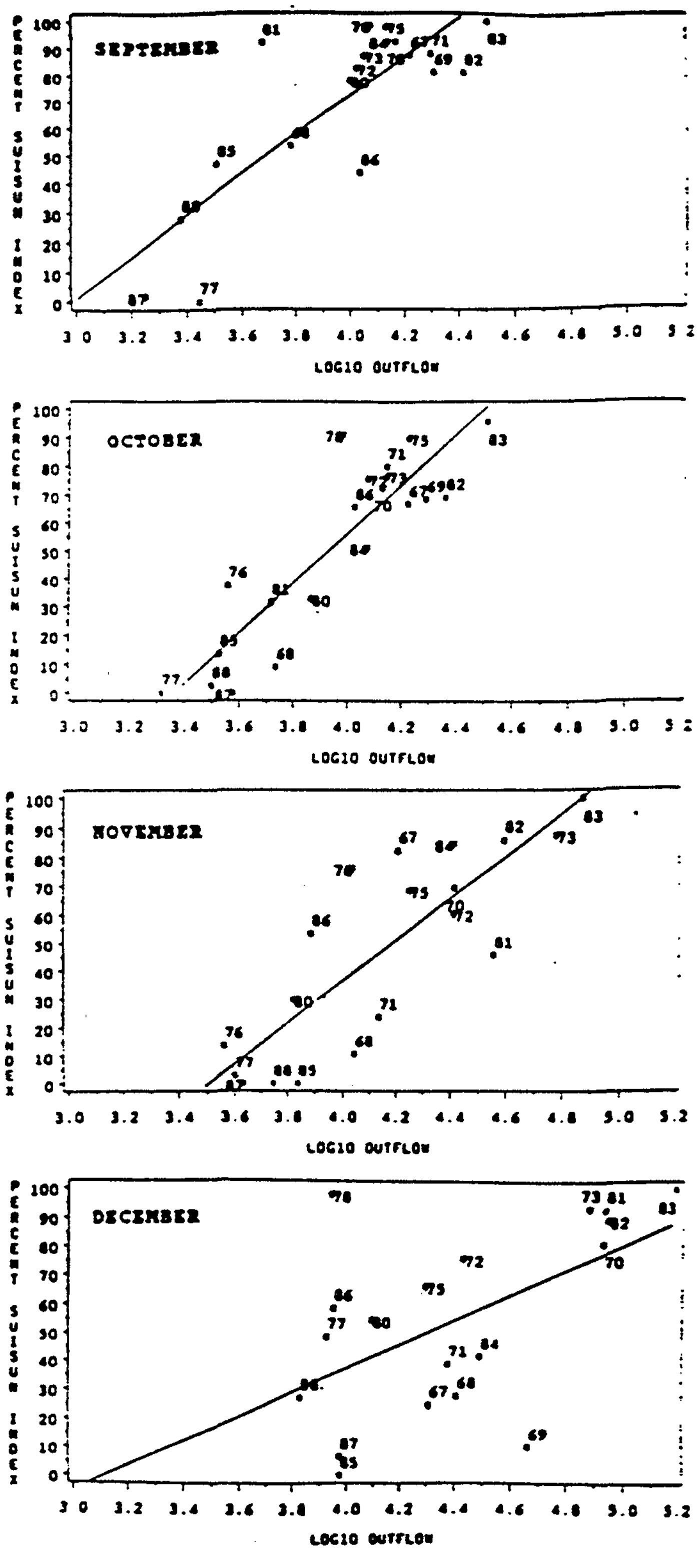

Figure 2. Relationship between the portion of the delta smelt population occurring west of the delta and log delta outflow during the survey month. Data are for the fall midwater trawl survey. For arcsine transformed percentages, R^2= .640 for September, .763 for October, .708 for November and .336 for December.

In late winter and spring, as the spawning period approaches, adult delta smelt disperse widely into freshwater, as far upstream in the Delta as Mossdale on the San Joaquin River (Radtke 1966) and (as indicated by trawling and seining during recent chinook salmon, Oncorhynchus tshawytscha, surveys) the mouth of the American River on the Sacramento River (Tables 2 and 6).

Delta smelt live principally in the upper portion of the water column. During a 1963-1964 survey of delta fish populations a 10 foot by 10 foot surface trawl captured 1960 delta smelt while a 15 foot by 5 foot otter trawl only captured 461 delta smelt. These results were obtained despite the otter trawl constituting 60 percent of this surveys effort of about 1800 tows (Radtke 1966, Turner 1966).

ABUNDANCE

Information from five Interagency Ecological Study Program monitoring programs and one University of California program was summarized to evaluate recent trends in delta smelt abundance:

1. the summer townet survey for young striped bass,
2. the fall midwater trawl survey for young striped bass,
3. the San Francisco Bay-Outflow Study's monthly midwater trawl survey,

Table 6. Catch of Delta Smelt by midwater trawl in the Sacramento River at Clarksburg, 1976-1981. This site has not been sampled in more recent years. N/M means not measured. Lengths in mm.

		May			June			July	
Year	Catch	Mean Length	No. Tows	Catch	Mean Length	No. Tows	Catch	Mean Length	No. Tows
1976	218	79	147	69	80	342	7	84	94
1977	242	N/M	443	117	N/M	550	0		95
1978			0	8	82	127			0
1979			0	15	78	100			0
1980			0	6	84	240			0
1981			0	29	80	139			0

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4. the seine and midwater trawl monitoring of young chinook salmon,
5. "salvage" of fish at the State and Federal water project fish screens in the south Delta, and
6. the University of California, Davis, Suisun Marsh fish survey.

While these data sets all provide information on delta smelt abundance at the time and location of sampling, each has inherent strengths and weaknesses in depicting the true population trend. These strengths and weaknesses are discussed as appropriate in the subsequent sections of this report.

<u>Summer Townet Survey</u>

The Department has conducted semi-monthly tow net surveys in the Delta and Suisun Bay, from late June to early August, each year since 1959 (except 1966) to index the abundance of young striped bass. On each survey run, three tows are made at each of about 30 sites from San Pablo Bay upstream through most of the Delta (Figure 3). Each survey run takes 5 days, and runs are made at 2-week intervals until the young bass average 38 mm (1.5 inches) in length. The number of runs has varied from two to five annually . The sampling gear and methods are described in detail by Calhoun (1953), Chadwick (1964), Turner and Chadwick (1972) and Stevens (1977). Catches of delta smelt are a by-product of

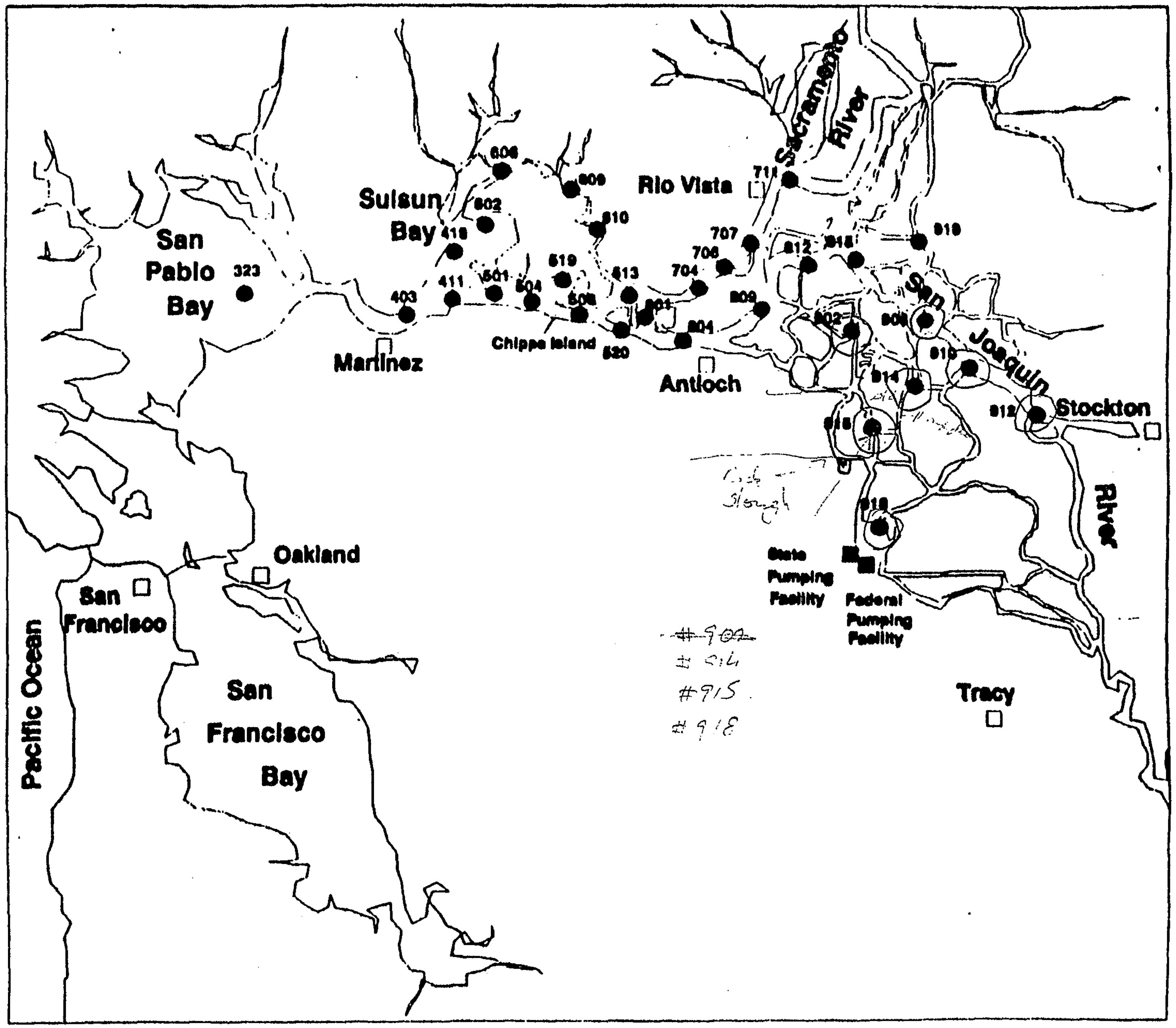

Figure 3. Summer townet survey sampling sites.

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this survey and records of these catches were kept in all years except 1967 and 1968. Annual abundance indices for delta smelt were calculated by summing, over all sample sites, the products of: total catch in all tows at a site x water volume in acre feet (Chadwick 1964) represented by that site. Delta smelt abundance indices were calculated only for the first two survey runs since runs 3,4, and 5 were not made in all years. The delta smelt abundance index is the mean of the abundance indices for the two runs after dividing by 1000 to scale the index for convenience. (Appendix C)

This survey provides good coverage of the delta smelt nursery and, in general, should yield an excellent index of young delta smelt abundance during early summer. In high flow years, however, the townet survey may undersample the population because many young smelt are washed downstream to San Pablo Bay or beyond.

The townet survey abundance index shows that annual production of young delta smelt has been quite variable since the survey began in 1959. The peak index of 62.5 in 1978 was 78 times greater than the lowest index of 0.8 in 1985. Abundance has been very low every year since 1983 including, the present year, 1990 (Figure 4). Similar low abundance indices occurred in several

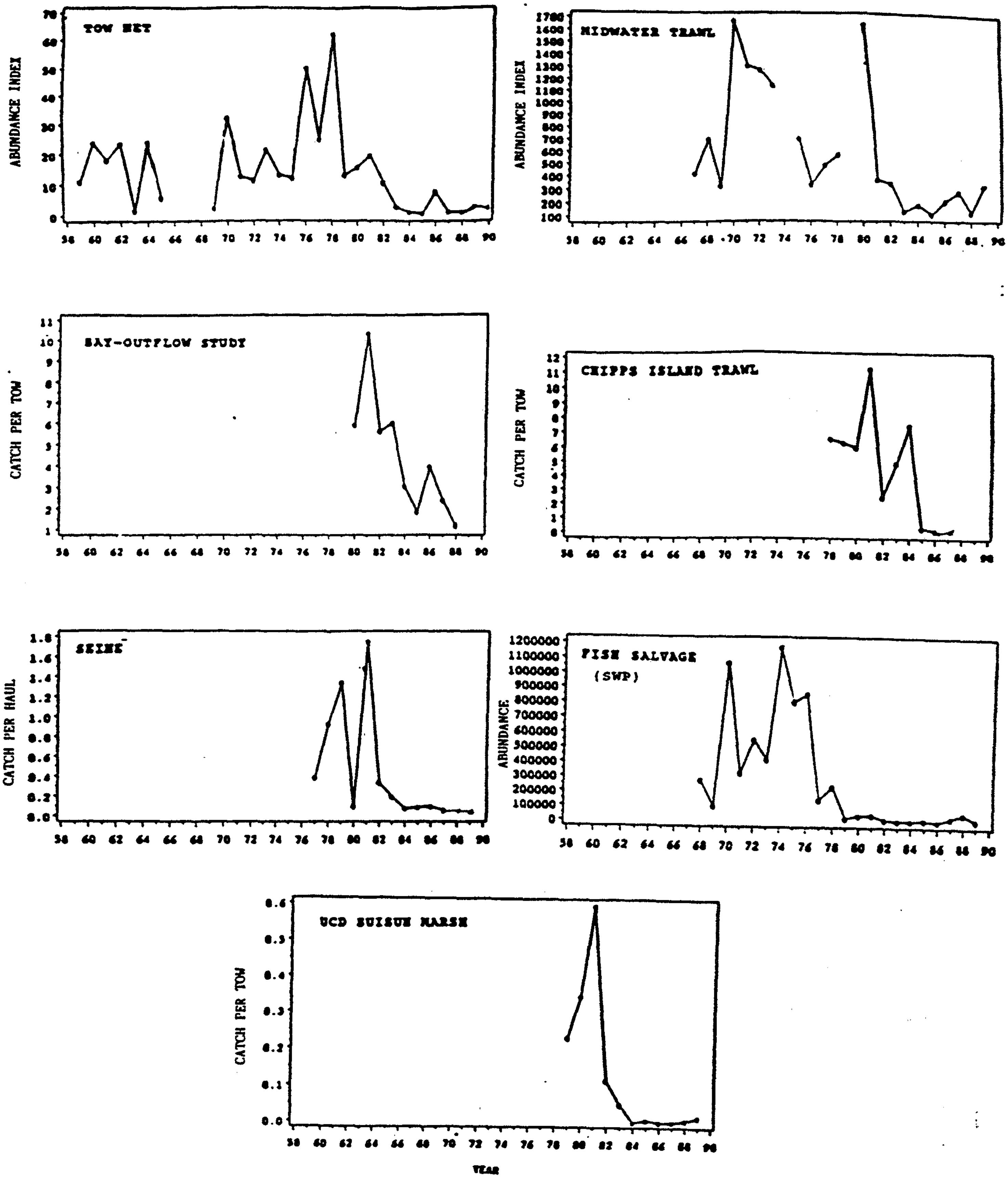

Figure 4. Trends in delta smelt as indexed by seven independent surveys.

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earlier years (1963,1965,1969), but never for consecutive years. Thus, the townet results indicate that there has been a collapse in the production of young delta smelt.

Fall Midwater Trawl Survey

Starting in 1967, a 12 ft X 12 ft midwater trawl has been used to measure abundance of young-of-the-year striped bass and other species, including delta smelt, during the fall. About 87 sites are sampled from San Pablo Bay upstream to Rio Vista on the Sacramento River and Stockton on the San Joaquin River (Figure 5; Stevens 1977). Originally, the midwater trawl survey was done monthly from August or September through the following March. However, due to extraneous variability in striped bass abundance indices caused by pulses of high winter runoff, sampling has been restricted since 1980 to September through December. Surveys were not conducted in 1974 or 1979 or in November 1969 and September and December 1976.

Delta smelt, which on average are smaller than young striped bass during the fall, probably are at least equally vulnerable to capture by this survey. This survey provides reasonable coverage of the delta smelt population and should yield reasonable measures of the ultimate success of each year class.

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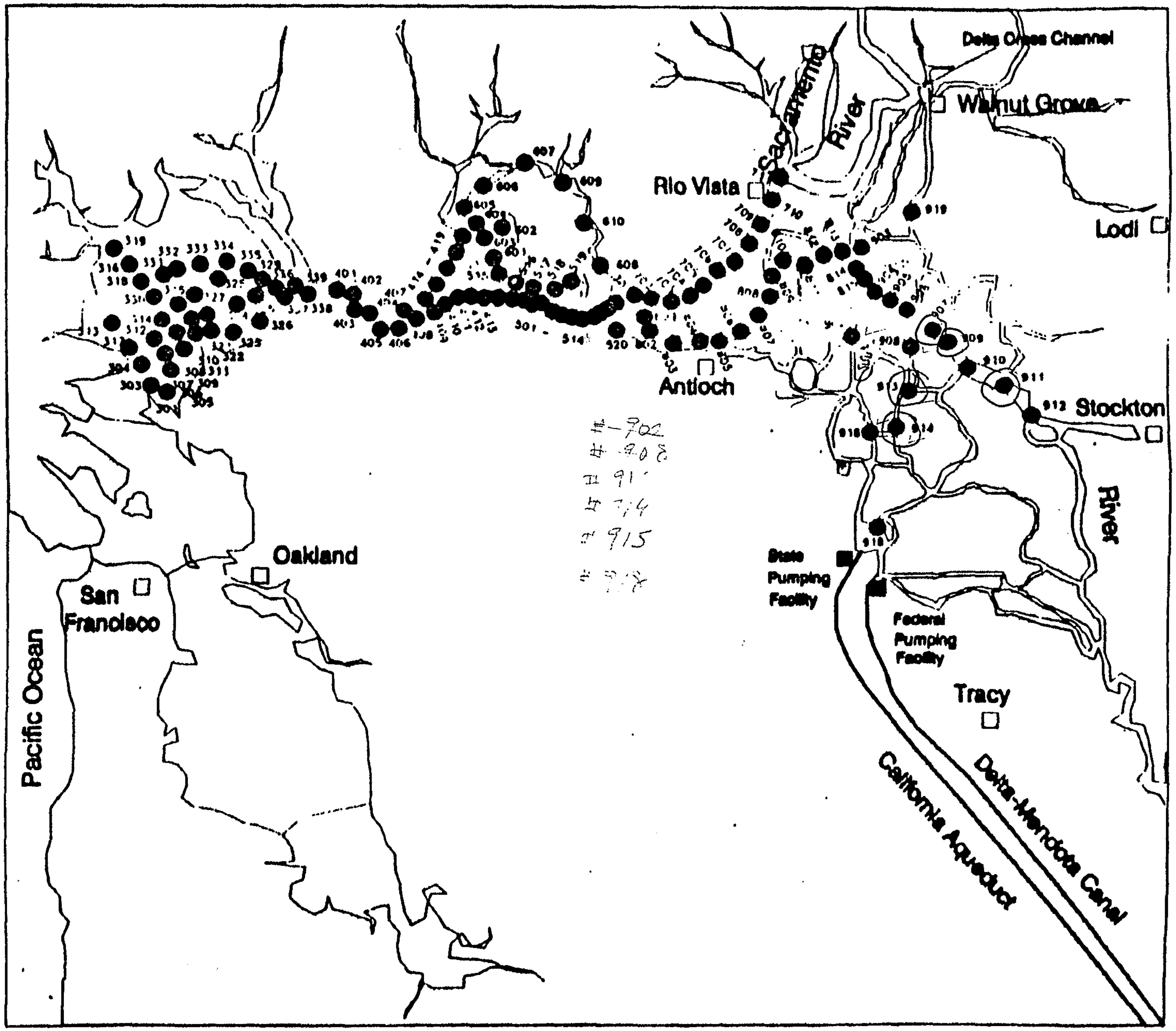

Figure 5. Fall midwater trawl survey sampling sites.

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Monthly abundance indices for delta smelt were calculated by summing, over all sampling sites, the product of: the mean catch per 12 minute tow in 17 subareas of the Estuary x the water volume in each subarea (Appendix D). The annual total abundance index is the sum of the monthly indices for September through December. Abundance indices for the surveys missing in 1969 and 1976 were estimated by interpolation or extrapolation of the months actually sampled.

Like the summer townet survey, the fall midwater trawl survey indicates that abundance of delta smelt has been highly variable, and has suffered a major decline (Figure 4). The peak fall index of 1678 occurred in 1970 and was 15 times greater than the minimum fall index of 109 which occurred in 1985. A general downward trend in fall abundance appears to extend back to the peak population of 1970 interrupted by a high index in 1980. The fall index has been consistently low since 1983 and from 1983 to 1988 was lower than in any previous year.

San Francisco Bay - Outflow Study

Midwater trawl catches of delta smelt by the Interagency Ecological Study Program's San Francisco Bay - Outflow Study provide yet another set of delta smelt abundance measures. These measures are based on catches of smelt as small as 25 mm up to adult size and are available from 1980 through 1988. They are based on monthly sampling (12-minute tows) at 42 locations extending from South San Francisco Bay to the western Delta (Figure 6).

The Bay-Outflow Study survey is comprehensive in that it samples monthly throughout the year. Its main deficiency in measuring delta smelt abundance is that it does not sample in the Delta east of Antioch and Collinsville; thus, a portion of the delta smelt's geographical range is not covered. This is particularly important in dry years when the population is concentrated in the Delta.

Typically, the Bay-Outflow survey's delta smelt catches peak from August to October as the new year class grows to a size at which they become vulnerable to capture by the sampling gear (Table 7). Average catches remain moderate through March and then decline into May when the bulk of the adults are spawning upstream from the sampling area and begin to die out. A few remaining adults and the next year class appear in the catches in June and July.

Bay survey catches show a striking decline in delta smelt abundance after 1981 (Figure 4). The 1981 catch rate was about twice that for 1980 but since 1981 there has been an irregular but persistent decline leading to a catch rate in 1988 that was only about one-tenth that for 1981. All of the catch rates since 1984 have been lower than in any previous year. The trend in catch frequency is consistent with the trend in annual catch rates. From 1981 through 1984, delta smelt were caught during all monthly surveys (Table 7). During 1985 and 1986 they were caught during 9 and 10 surveys, respectively. Delta smelt were caught only during 6 of the 12 monthly surveys in 1987 and only during 5 surveys in 1988.

Based on the Bay-Outflow Study data, the current population of delta smelt is distinctly depressed. Part, but by no means all, of this depression likely is due to incomplete coverage of the delta smelt's geographical range: four of the five years since 1983 have been low flow years and the population has been concentrated in the Delta.

Salmon Survey Trawl and Seine Catches

The Interagency Program has used midwater trawl and seine surveys to measure annual abundance of young chinook salmon. These surveys are currently administered by the U.S. Fish and Wildlife Service. Delta smelt are an incidental catch in these salmon surveys.

The primary trawl survey has been conducted from April through June, since 1976, at Chipps Island in upper Suisun Bay. Data from this survey currently are available through 1987. A major deficiency of delta smelt abundance measures from this trawl survey is that the survey only samples at one location, thus the indices are affected by annual differences in delta smelt distribution. Nevertheless, the catches may still reflect major changes in population status.

The seine survey generally has sampled about 23 sites at beaches in the Delta and Sacramento River upstream to the mouth of the American River (Figure 7). This survey is run several times each month from January to April, May, or June. Data currently are available from 1977 to 1989. Since the sampling is entirely in the Delta and the Sacramento River and in late winter and spring, catches primarily reflect numbers of delta smelt undertaking their spawning migration, although, occasionally, young smelt around 20-30 mm long also have been taken.

As for the other data sources, catches of delta smelt in the salmon surveys were low during the most recent years. In the Chipps Island trawl survey, the catch of delta smelt fell dramatically in 1985 (1984 year class) and remained low in 1986 and 1987 (Figure 4 and Table 8). Catches during these years were considerably lower than in any previous year except 1977 when a drought caused salinity encroachment and most of the delta smelt

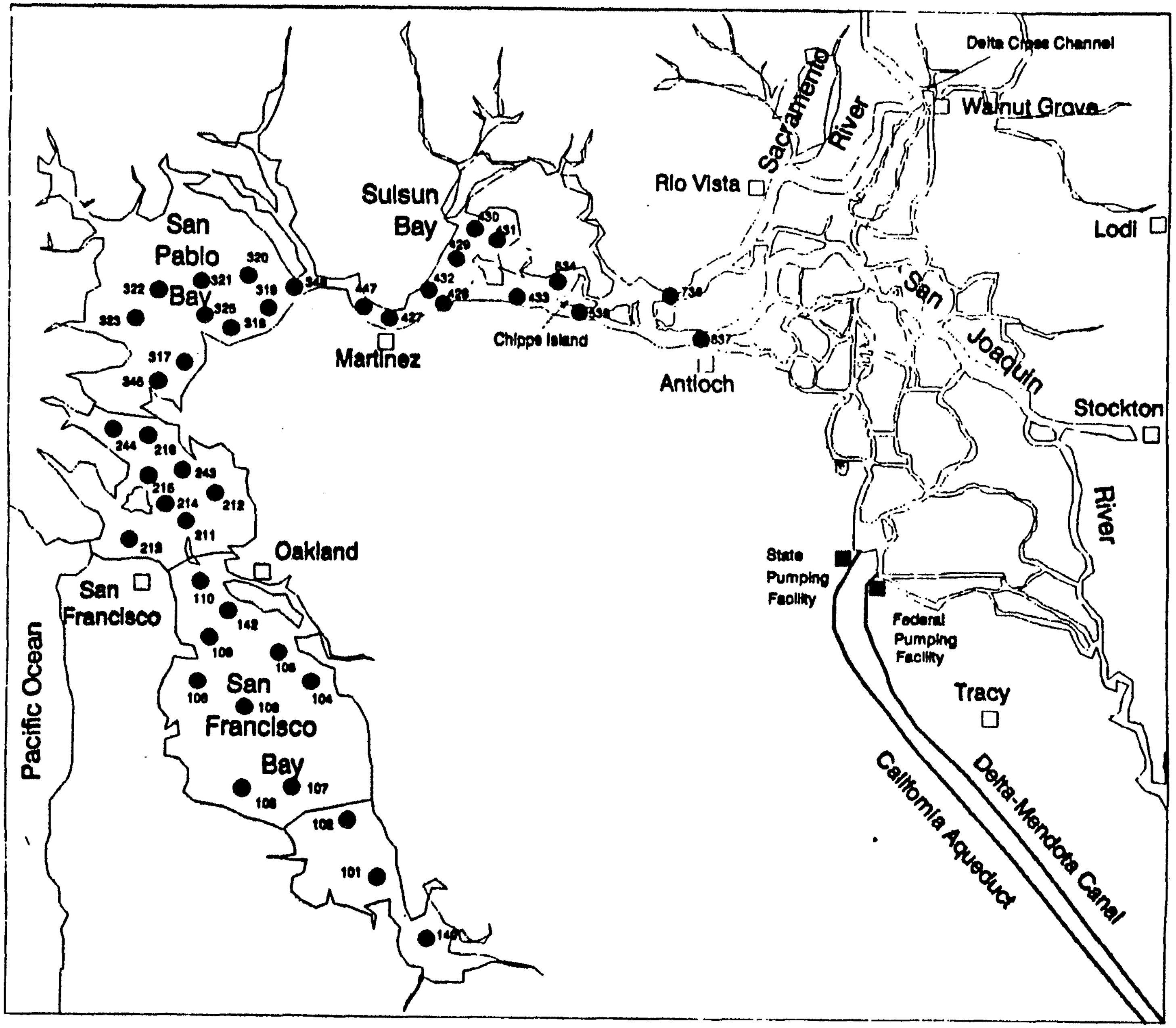

Figure 6. San Francisco Bay - outflow survey sampling sites.

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Table 7. San Francisco Bay - Outflow study catches of delta smelt by month and year.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	1	4	37	2	0	53	31	51	20	36	4		239
1981	27	46	26	19	3	23	15	39	53	19	11	26	307
1982	41	15	9	5	4	4	35	13	7	9	7	22	171
1983	30	12	41	5	1	2	1	15	29	66	14	3	219
1984	2	5	14	21	4	0	5	11	29	5	6	5	107
1985	5	1	1	0	0	1	4	2	1	1	0	21	37
1986	1	3	14	0	0	1	1	23	21	29	9	6	108
1987	6	0	2	1	0	0	6	0	4	0	25	0	44
1988	0	2	1	0	0	0	0	0	16	5	6	0	30
Total	113	88	145	53	12	84	98	154	180	170	82	83	1262

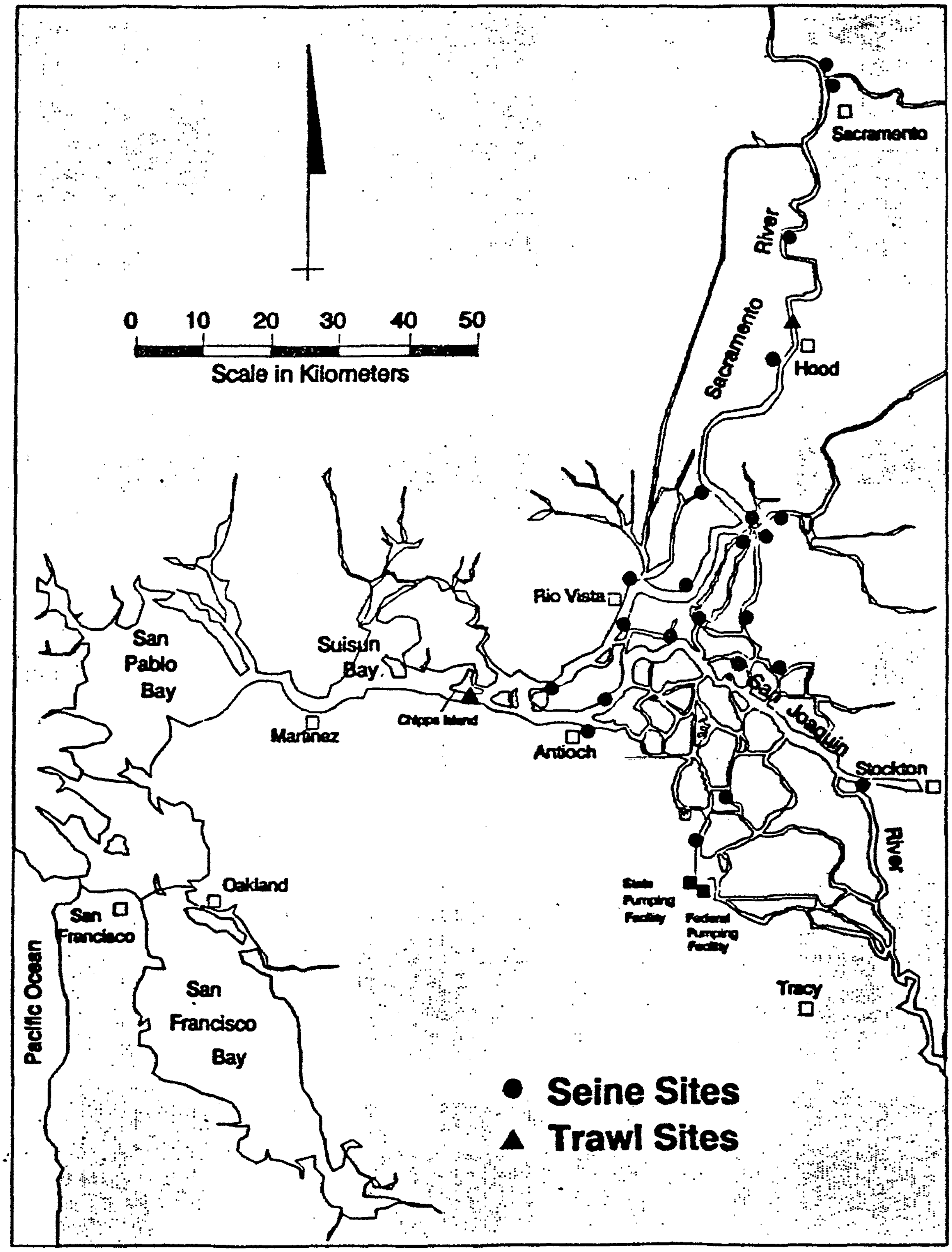

Figure 7. Sampling sites of the salmon trawl and seine surveys.

Table 8. Catch of delta smelt per tow during the chinook salmon trawl survey in the western Delta at Chipp's Island, April-June, 1976-1986. Number of tows in parentheses.

Year	April	May	June	Mean Apr-Jun
1976		3.38(76)	15.54(188)	
1977		0.00(174)	0.01(227)	
1978	2.48(101)	2.28(90)	15.06(174)	6.61
1979	3.83(77)	1.18(78)	14.02(190)	6.34
1980	0.69(65)	0.49(81)	16.88(252)	6.02
1981	14.15(52)	3.69(61)	16.11(124)	11.32
1982	1.46(43)	4.07(121)	2.08(125)	2.54
1983	7.73(67)	4.27(128)	2.85(146)	4.95
1984	15.94(73)	1.85(99)	4.78(164)	7.52
1985	0.91(86)	0.05(298)	0.11(45)	0.36
1986	0.23(95)	0.19(288)	0.28(149)	0.23
1987	0.25(159)	0.21(290)	0.00(43)	0.15

population probably moved upstream from the sampling site. The relatively high average catch of more than seven delta smelt per tow in 1984 (1983 year class) also is inconsistent with the population trend depicted by the broader based surveys and again may reflect an anomalous smelt distribution relative to the single sampling location.

In the seine survey, the lowest average catches of adult delta smelt occurred in 1980 and 1984-1989 (Figure 4 and Table 9). The reason for the low catch in 1980 (1979 year class) is unknown. However, the persistent low catches from 1984-1989 (1983-1988 year classes) are consistent with the population decline exhibited by the fall midwater trawl and summer townet surveys.

Salvage at SWP and CVP Fish Screens

Fish salvage operations at the State Water project (SWP) and the U.S. Bureau of Reclamation's Central Valley Project (CVP) fish screens provide huge samples of fish populations in the Delta; however, a major deficiency relative to measuring fish population trends is that all of the sampling occurs at only one location so the samples are affected by annual variations in the geographical distribution of each species. The salvage is also affected by seasonal and annual variations in water export rates, which affect numbers of fish that are diverted and screening

Table 9. Mean monthly catch of adult delta smelt per haul during the chinook salmon seine survey in the Sacramento-San Joaquin Delta, January-April 1977-1987.

Year	Mean monthly catch per haul	No. hauls
1977	0.39	152
1978	0.93	105
1979	1.34	250
1980	0.10	359
1981	1.75	397
1982	0.34	352
1983	0.20	321
1984	0.08	291
1985	0.09	321
1986	0.10	222
1987	0.06	238
1988	0.01	233
1989	0.01	281

efficiency. Also, at times, particularly before 1979 at the CVP, there have been species identification and other data quality problems. Nevertheless, considering the lengthy period of fish salvage information, the records provide another independent, albeit imperfect, source of information on the delta smelt population trend.

Salvage of delta smelt has been monitored since 1968 at the SWP fish screens and since 1979 at the CVP screens. Estimates of total smelt (delta smelt and longfin smelt) salvage provide additional information on smelt trends at the CVP back to 1973. Salvage estimates represent numbers of fish screened from the water that is exported from the Delta, but over-represent numbers of fish that are actually saved because many of these salvaged fish die due to the handling and trucking that is necessary to return fish to the Delta, and to predation by larger fish at the release sites.

Total salvage is estimated from estimates for consecutive periods (typically 2 hours long) based on the salvage rate (fish per minute entering the holding tanks) during each period. These salvage rates are estimated from fish counts ranging from one minute to the total length of the period. Sample counts are expanded to account for the amount of water exported when counts were not made. Because numbers of fish salvaged are affected by the amount of water diverted, salvage per-acre-foot diverted was also examined.

At the SWP, delta smelt salvage estimates were less than 300,000 fish in the initial two years of sampling, 1968 and 1969, but exceeded 300,000 fish, ranging up to more than 1 million fish in 1970 and 1974 (Figure 8). In 1977, there was a precipitous decline to 146,000 fish from 856,000 fish the previous year. Salvage increased to about 238,000 delta smelt in 1978; however, since 1979, the salvage of delta smelt has been consistently low, less than 60,000 fish, and as low as 3,600 fish in 1986.

At the CVP, the estimated salvage of delta smelt was on the order of 45,000 fish in 1979 and 1980, when smelt species identification began (Figure 9). In 1981, the estimate increased to about 275,000 fish, but since 1982, salvage has been very low, ranging from 2,800 to 34,000 fish.

Despite the lack of smelt species identifications, total smelt salvage estimates suggest that, as at the SWP, CVP salvage of delta smelt tended to be greater from 1973 to 1978 than it has been since 1979. Except in very recent years when the delta smelt population has been very low, the vast majority of identified smelt have been delta smelt at both the CVP and SWP (Table 10). All of the pre-1979 CVP estimates of total smelt

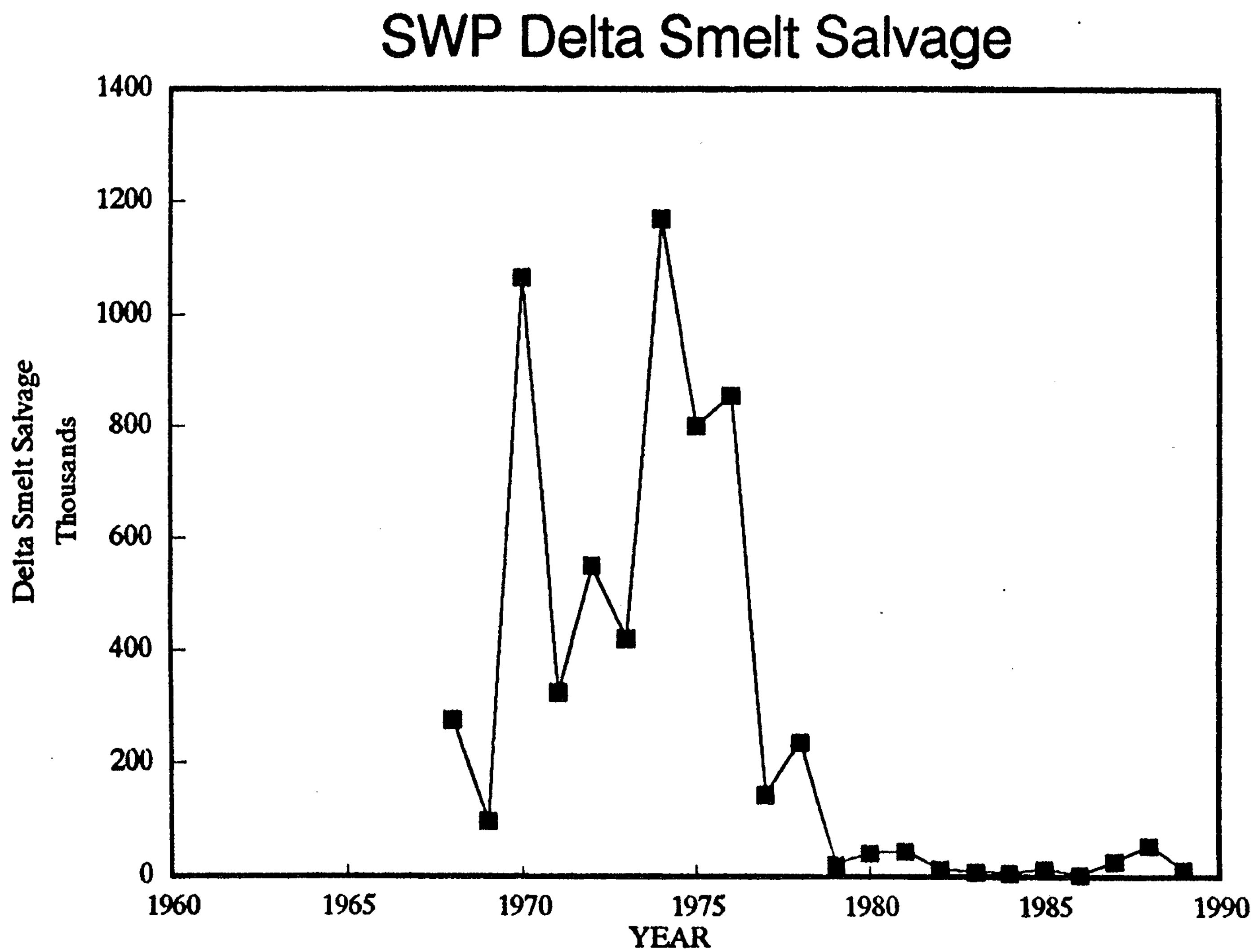

Figure 8. Annual salvage estimates for delta smelt at the State Water Project fish screens.

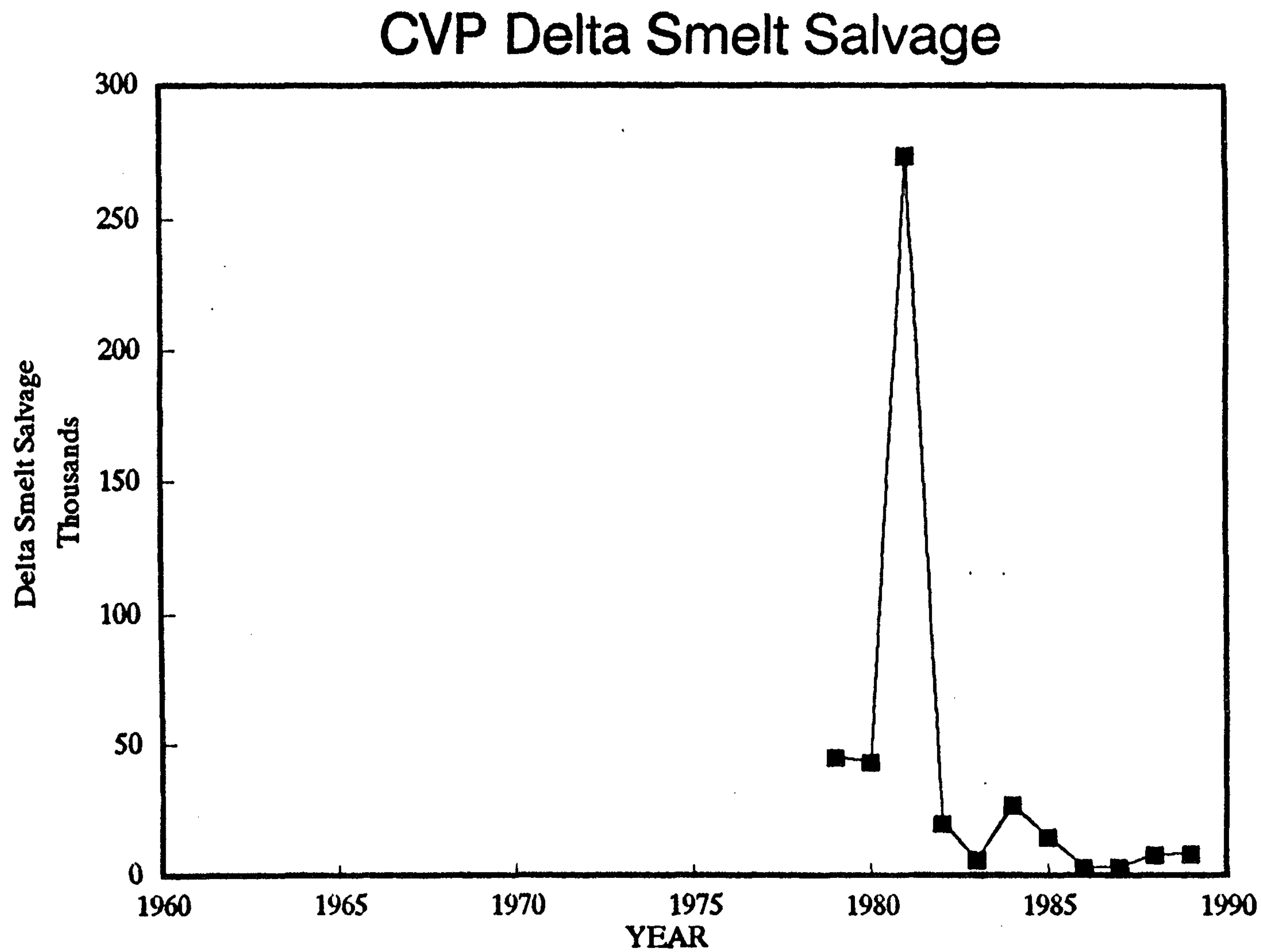

Figure 9. Annual salvage estimates for delta smelt at the Central Valley Project fish screens.

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Table 10. Percentage of smelt salvage at State and Federal Water Project fish screens formed by delta smelt, 1968-1989.

Year	State Water Project Percent delta smelt	Central Valley Project Percent delta smelt
1968	100.0	
1969	99.8	
1970	97.3	
1971	30.0	
1972	98.9	
1973	100.0	
1974	100.0	
1975	100.0	
1976	100.0	
1977	78.6	
1978	98.5	
1979	78.3	54.9
1980	81.6	100.0
1981	94.8	99.9
1982	99.6	100.0
1983	96.5	99.0
1984	88.5	55.4
1985	41.8	80.6
1986	63.0	94.3
1987	34.7	7.4
1988	28.6	54.7
1989	16.4	25.4

salvage varied from about 130,000 to 311,000 fish, a level equaled subsequently only in 1981 (Figure 10).

Overall, salvage at the SWP and CVP fish screens has trended substantially downward since 1976 (Figures 4, 8, and 9), despite a trend of increasing water exports (Figure 11) which would lead to increased salvage of fish if the smelt population was stable or increasing. The one anomaly in this trend is the estimated salvage of 275,000 delta smelt at the CVP screens in 1981.

When sampling effort is considered, by calculating numbers of smelt salvaged per acre-foot of water diverted, pre-1979 abundance patterns appear to change somewhat, but, as for total salvage, subsequent salvage per-unit-effort measures are extremely low (except for 1981 at the CVP) (Figure 12).

Hence, the CVP/SWP salvage records are consistent with the other data sets indicating that a major decline has occurred in the delta smelt population; however, considering the sampling deficiencies (all sampling in one location, seasonal and annual variability in water export rate, and data quality control problems) in these data bases, the midwater trawl and townet surveys undoubtedly provide a better depiction of the timing and magnitude of decline.

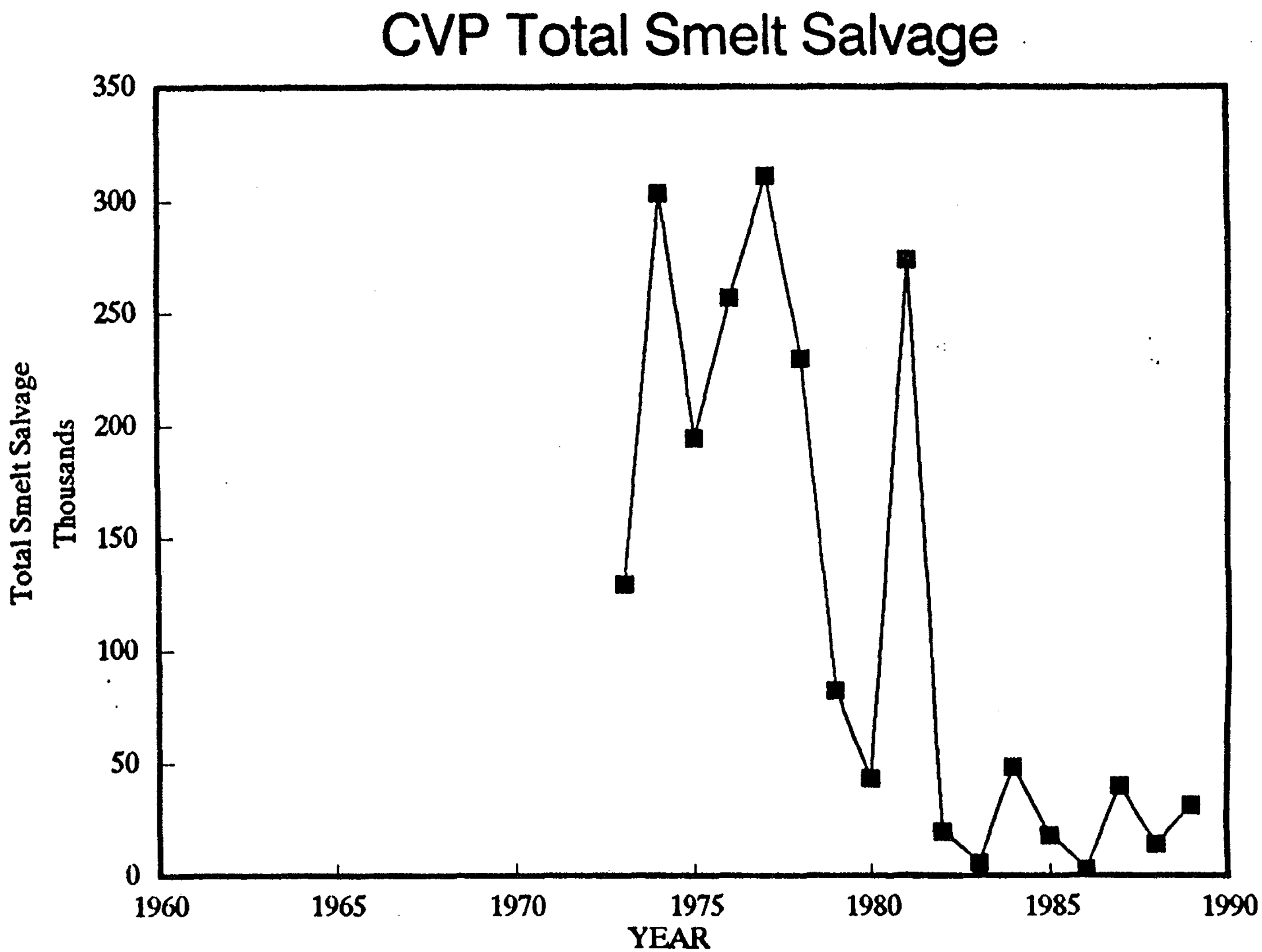

Figure 10. Annual salvage estimates for total smelt (delta smelt and longfin smelt) at the Central Valley Project fish screens.

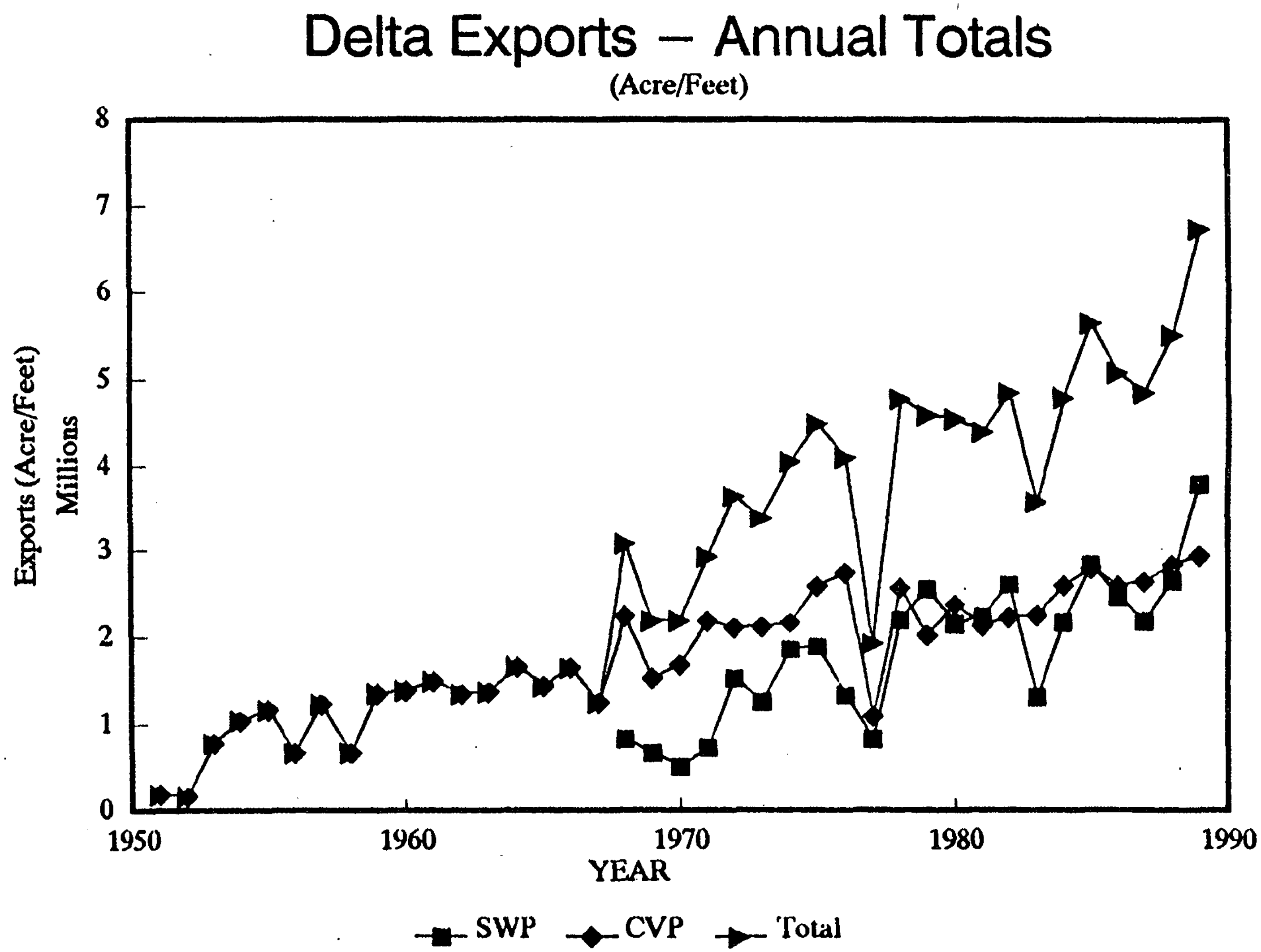

Figure 11. Trend in annual water exports by the State Water Project and Central Valley Project.

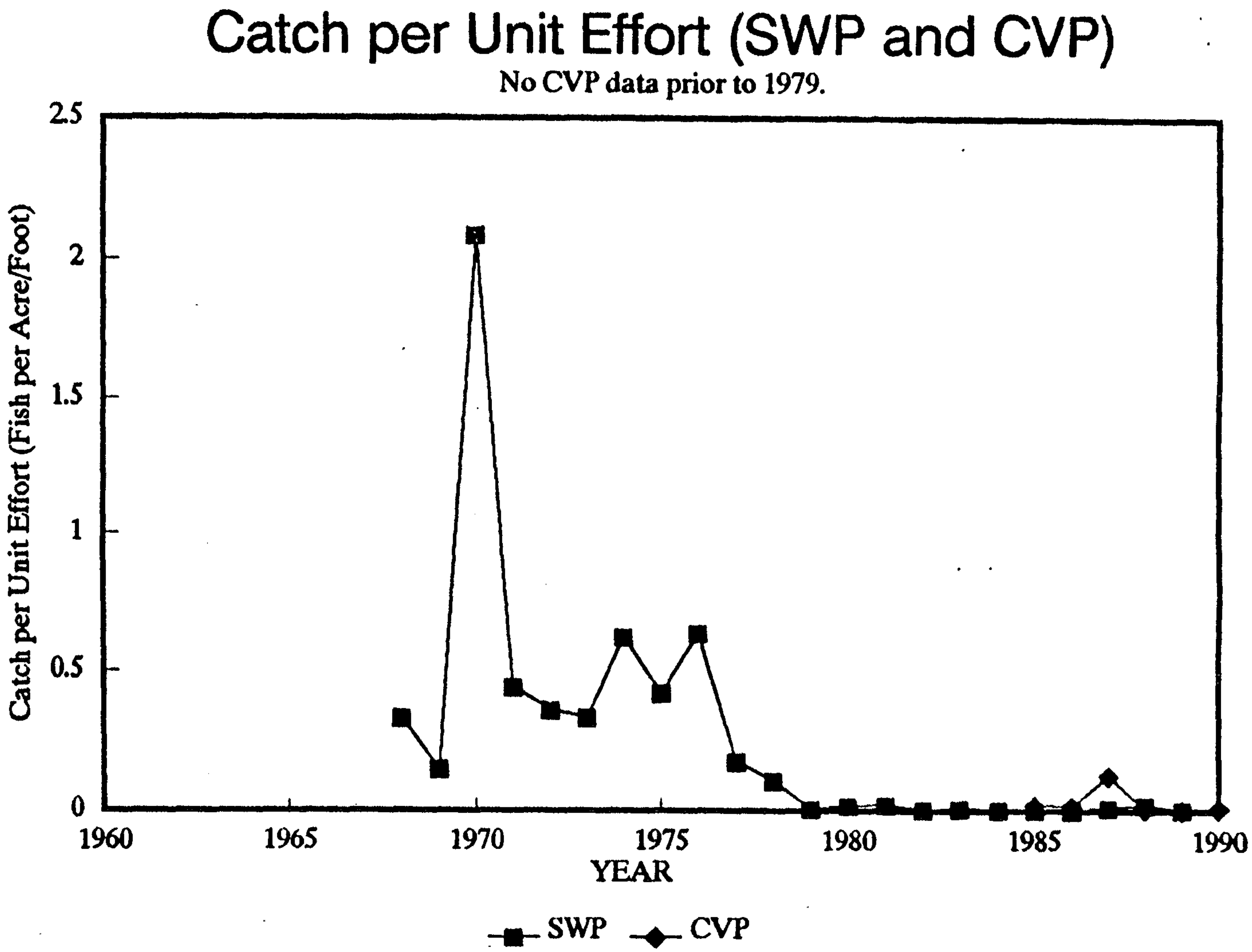

Figure 12. Salvage of delta smelt per acre foot of water diverted by the State Water Project and Central Valley Project.

UC Davis Suisun Marsh Survey

Drs. Peter Moyle and Bruce Herbold and classes at the University of California, Davis have used otter trawls to sample fish populations in Suisun Marsh sloughs since 1979. They have provided us with their delta smelt abundance index for the Marsh based on the number of smelt caught per tow each year. Over the 11-year survey, the UC Davis classes collected 465 delta smelt, all but one of which was collected before 1984 (Figure 4). Delta smelt were rather scarce when the survey began in 1979. Catches improved considerably in 1980 and 1981 with the peak catch of 229 fish occurring in 1981. Subsequently, in 1982 and 1983, delta smelt abundance declined below the 1979 level, and since 1984 they have been virtually non-existent.

Because the UC Davis sampling locations are limited geographically and because the geographical distribution of delta smelt varies annually, we believe that other data sources provide a better depiction of the overall population trend. However, the UC Davis survey is consistent with the other data sources in exhibiting a much lower current population of delta smelt.

Conclusions Regarding Delta Smelt Abundance Trend

All delta smelt abundance indices have declined in recent years, but the timing of their decline varies somewhat depending on which measure is used. The summer townet survey and fall midwater trawl survey provide the best geographical coverage of the delta smelt population; thus, they provide the best basis for evaluating population trends. Information from the other data sources confirms the general downward trend in delta smelt abundance and allowed additional insight into distribution patterns not covered by the summer and fall surveys.

Based on the summer and fall surveys, the delta smelt population has been consistently low every year since 1983. While the population had been as low or nearly as low in some previous years, no multiple year period of low abundance had occurred previously during the period of record beginning in 1959.

Looking at the decline by geographical areas (Figures 13 and 14), it is apparent that the delta smelt decline may have begun earlier in the south and east delta than in the rest of the Estuary. An earlier decline in these areas is consistent with the decline suggested by the fish salvage data from the water project diversions in the south Delta.

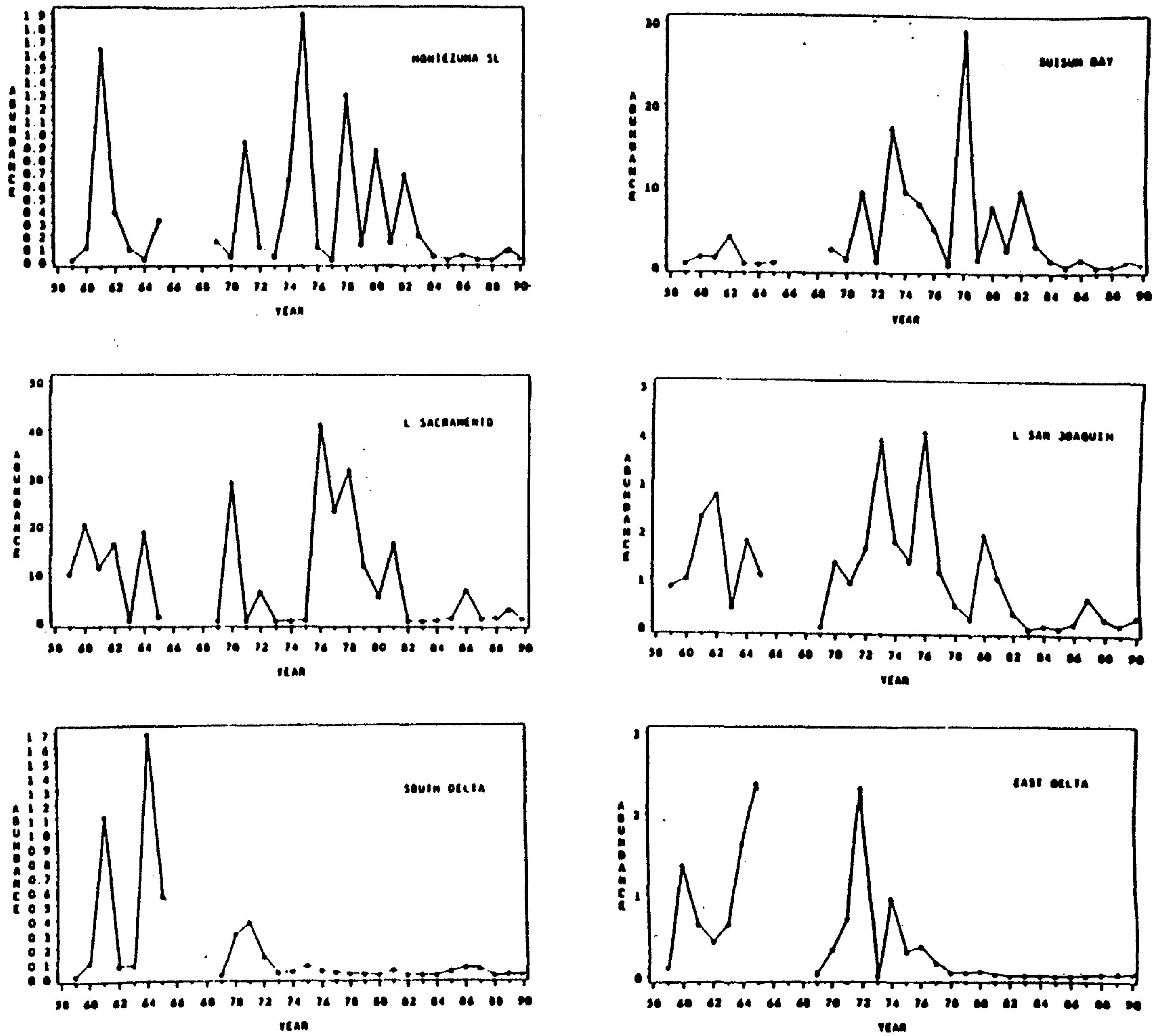

Figure 13. Abundance of delta smelt by area based on the summer townet survey. L. Sacramento is the Sacramento River between Collinsville and Rio Vista. L. San Joaquin is the San Joaquin River between Antioch and San Andreas shoal west of the Mokelumne River.

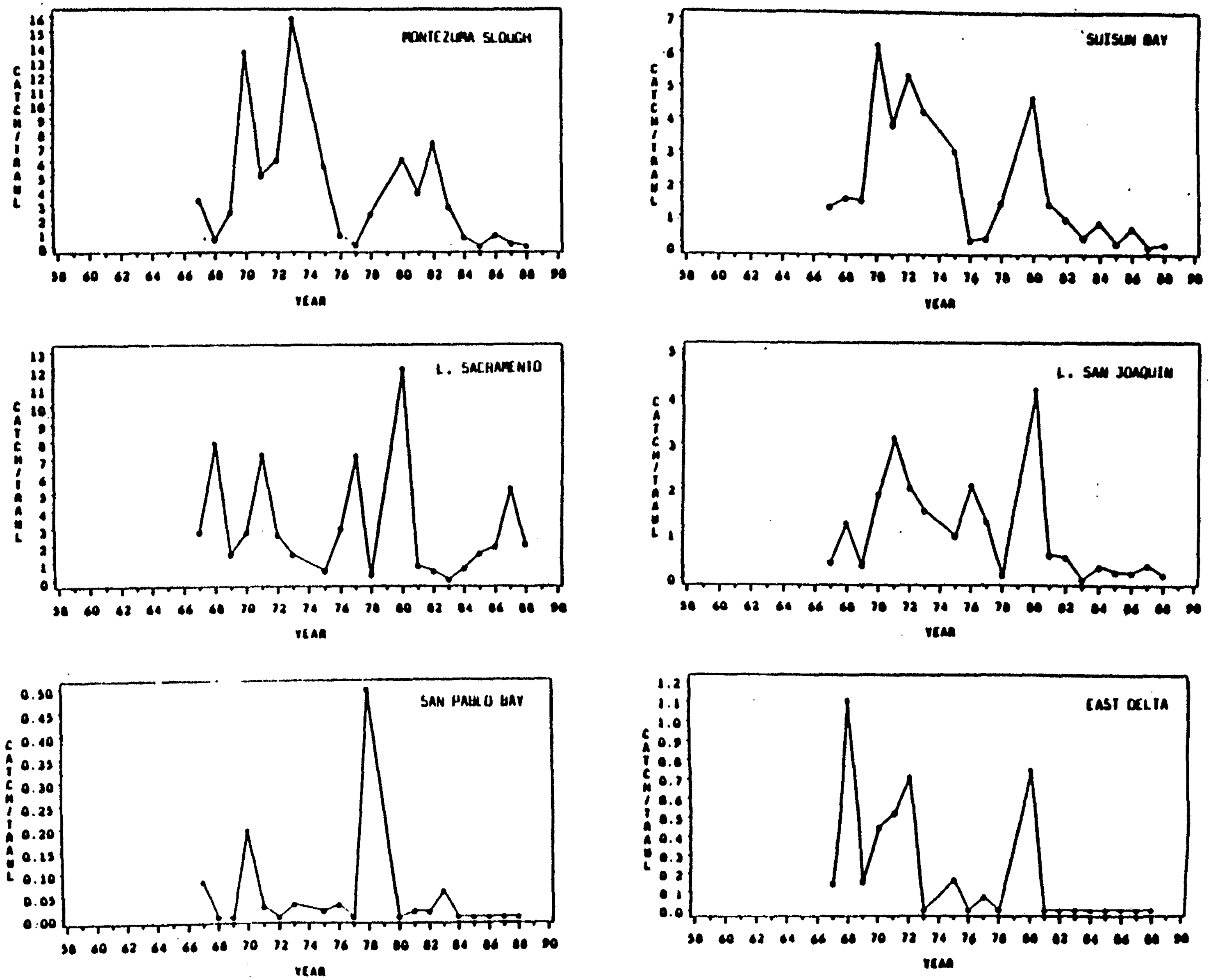

Figure 14. The catch-per-tow of delta smelt in the midwater trawl survey by areas comparable to those used for the townet survey (Figure) except for the addition of San Pablo Bay and the deletion of the South Delta which was not sampled after 1975.

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capturing them is not due to a diminishing of the delta smelt's range within the Estuary. Instead, the decline is simply due to reduced probability of capture associated with a general decline in abundance.

To determine if the apparent decline in delta smelt abundance was statistically significant, we used an Analysis of Variance (ANOVA) with Tukey's test for grouping years for which there are no significant differences. This analysis was based on logarithmic transformations of catch per tow in the townet and trawl surveys. The ANOVA demonstrated significant differences between years and the Tukey's ranking generally separated the recent years into a common group separate from earlier years although there were a few exceptions such as 1959, 1963 and 1969 in the townet survey groupings (Tables 11 and 12).

Population Size

To address the question of delta smelt abundance, we multiplied, for the fall midwater trawl survey, the ratio of delta smelt juveniles to young striped bass by rough estimates of striped bass population size which are available for 8 years. Using this approach, albeit imperfect due to unknown catch vulnerabilities, we estimate that the fall delta smelt population is now several hundred thousand fish (Table 13). In the early 1970s, estimates were on the order of 2 million fish.

Table 11. Tukey's studentized range test for detecting differences in $\log_{10}$ mean catch per tow of delta smelt by the townet survey. Means with the same Tukey grouping letter are not significantly different (p. <0.10).

Tukey Grouping	Mean	N	Year
A	0.56	174	1961
A B	0.53	167	1976
A B C	0.48	186	1962
A B C D	0.43	176	1971
A B C D	0.43	186	1964
A B C D	0.42	135	1960
A B C D	0.41	175	1975
A B C D	0.40	184	1978
B C D E	0.38	183	1980
B C D E	0.38	172	1974
B C D E	0.38	186	1970
B C D E	0.36	176	1982
C D E	0.35	152	1977
C D E	0.35	176	1981
C D E F	0.38	186	1965
D E F G	0.29	172	1972
D E F G H	0.27	178	1973
E F G H I	0.22	189	1979
F G H I	0.17	134	1959
F G H I	0.16	181	1986
G H I	0.14	186	1963
H I	0.12	151	1983
H I	0.11	182	1969
H I	0.10	161	1984
I	0.07	159	1988
I	0.07	175	1987
I	0.05	164	1985

Table 12. Tukey's studentized range test for detecting differences in $\log_{10}$ mean catch per tow of delta smelt for the midwater trawl survey. Means with the same Tukey grouping letter are not significantly different ($p < 0.10$).

Tukey Grouping							Mean	N	Year
A							0.31	326	1980
A							0.30	324	1973
A	B						0.25	295	1975
	B	C					0.20	385	1970
	B	C					0.19	404	1968
		C	D				0.17	390	1971
		C	D	E			0.17	364	1972
		C	D	E	F		0.14	335	1967
		C	D	E	F		0.14	332	1981
			D	E	F	G	0.11	332	1969
			D	E	F	G	0.11	478	1977
				E	F	G	0.10	456	1978
				E	F	G	0.10	358	1982
					F	G	0.08	364	1986
					F	G	0.08	353	1984
					F	G	0.07	386	1987
						G	0.05	370	1983
						G	0.04	358	1985
						G	0.04	369	1988

Table 13. Estimates of Delta Smelt abundance based on the ratio of Delta smelt abundance to young striped bass abundance in the fall midwater trawl survey multiplied by population estimates of young striped bass derived from a life table analysis.

Year	Striped Bass Index	Delta Smelt Index	Ratio Smelt: Bass	Striped Bass Population (in millions)	Delta Smelt Population (in thousands)
1968	4109	696	.17	1.8	300
1970	8144	1677	.21	8.1	1670
1971	9069	1306	.14	11.9	2670
1972	6101	1267	.21	12.7	2630
1975	4538	698	.15	1.6	240
1977	844	483	.57	0.4	230
1984	6584	181	.03	11.8	350
1985	1757	109	.06	4.7	280

Population Age Structure

We examined length-frequency data for the townet and midwater trawl surveys for 1977, 1978 and 1980 to learn more about the size and age structure of the population (Figures 16 and 17). In both data sets, two year classes of delta smelt were evident. The juveniles from the current year's production form one group in the size range of 15 mm to about 65 mm in summer and up to about 90 mm in the fall. Second groupings of larger smelt up to 130 mm indicate that a few adults survive the rigors of spawning and live into the following winter. However, since these larger adults are so scarce, one-year old fish form almost the entire spawning population each year.

FACTORS AFFECTING DELTA SMELT ABUNDANCE

What factors regulate abundance of each year class of delta smelt? Considering that most delta smelt spawn only once, the abundance of the previous year class and its egg production is potentially important. We evaluated the potential role of egg production by examining spawner-recruit relationships using the summer townet survey data alone, a combination of the summer townet data and the midwater trawl data, and the midwater trawl data alone (Figure 18). In the best case, that for the midwater trawl data alone, the spawning stock abundance accounted for

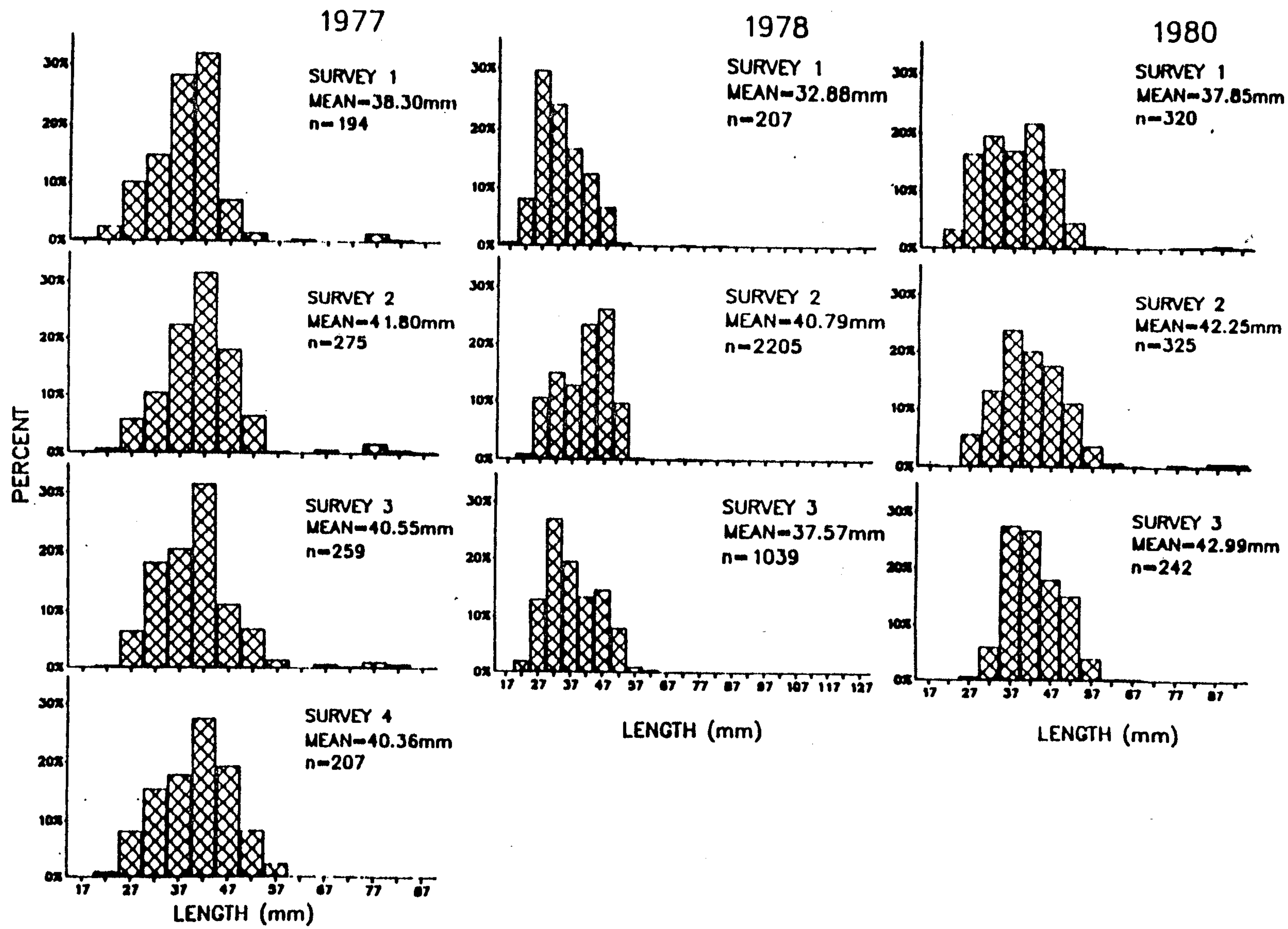

Figure 16. Length frequency distribution of delta smelt catches in the 1977, 1978 and 1980 townet surveys.

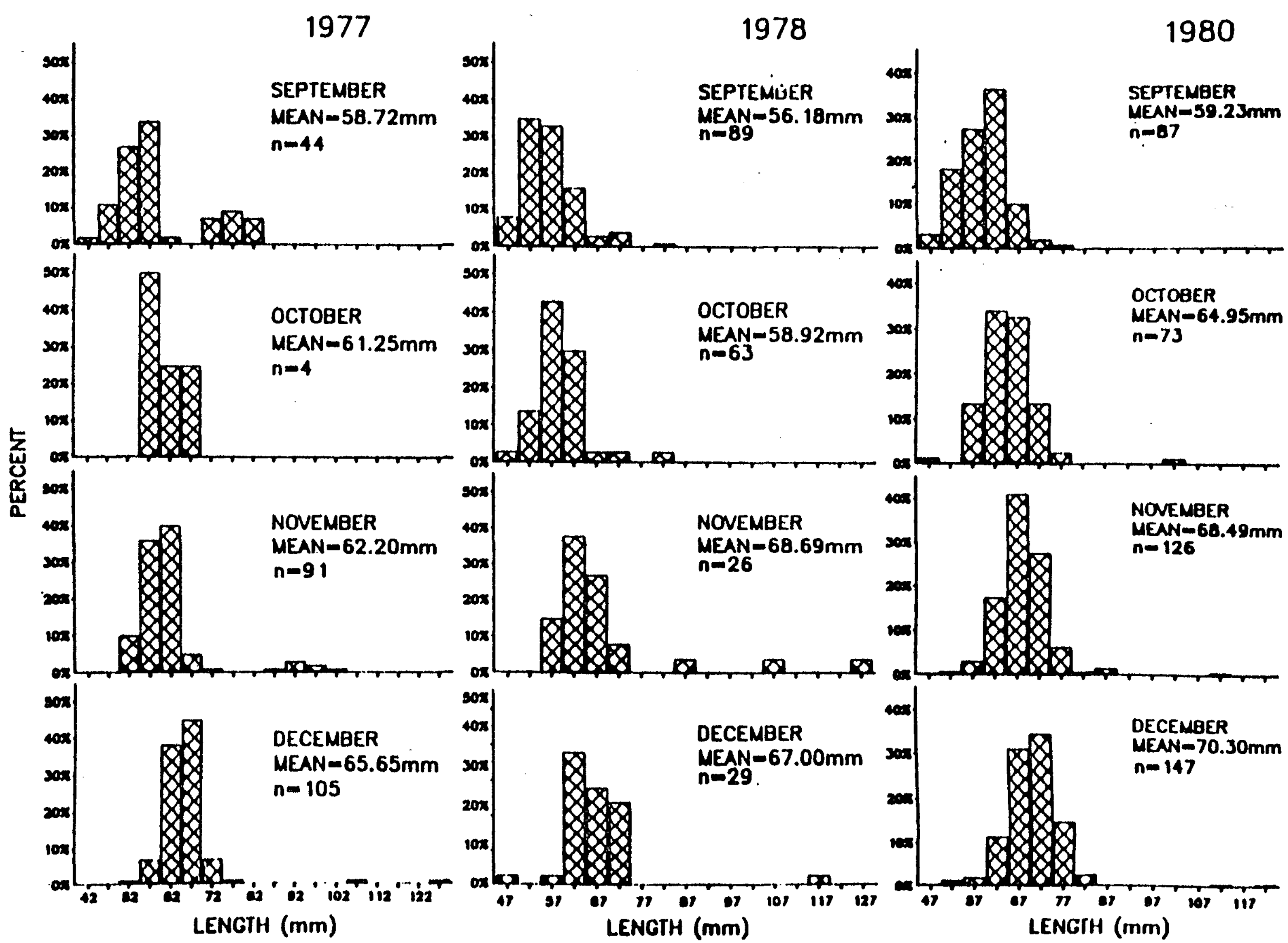

Figure 17. Length frequency distribution of delta smelt catches in the 1977, 1978 and 1980 midwater trawl surveys.

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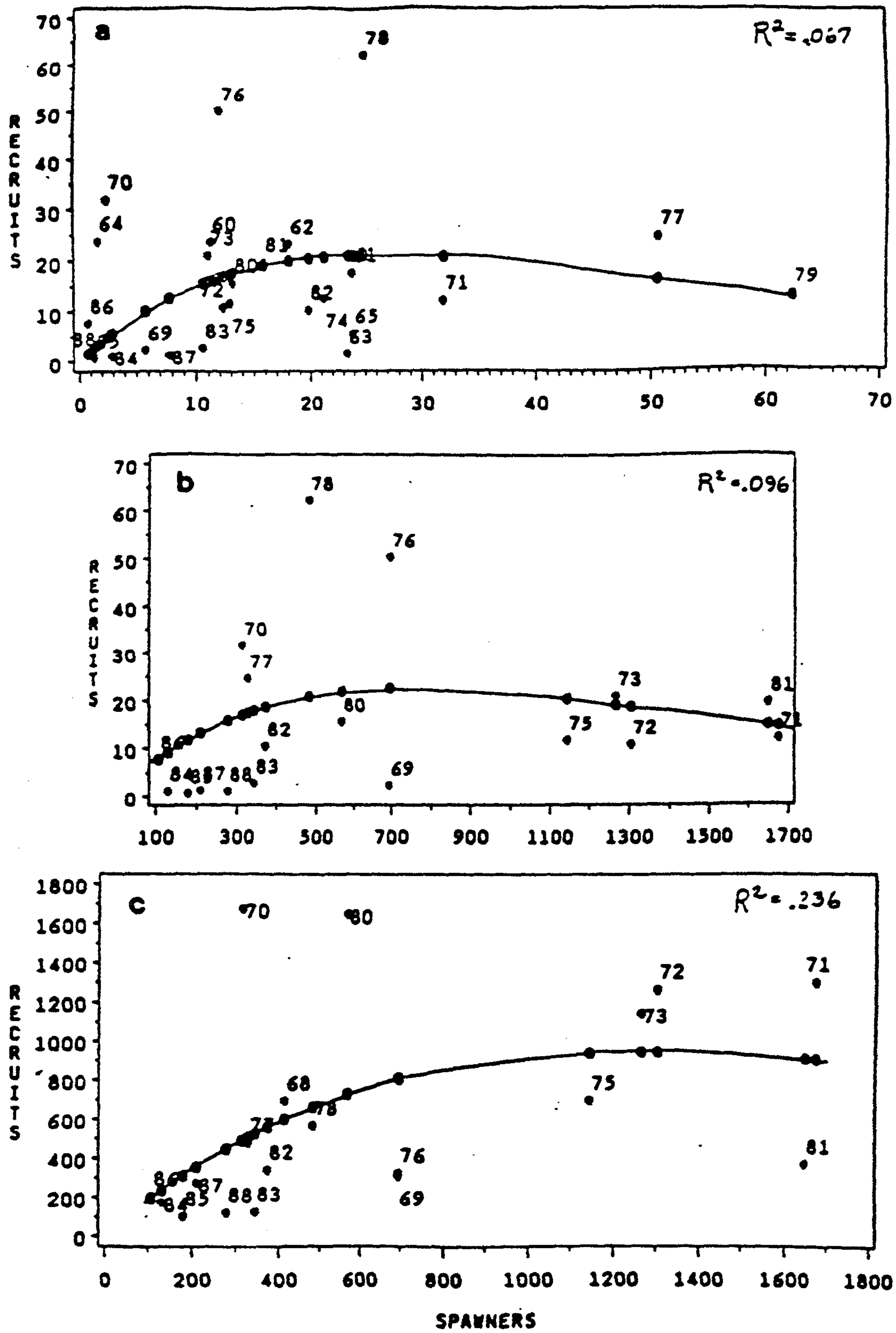

Figure 18. Spawner-recruit relationships for delta smelt: (a) the townet index (spawners) and the townet index for the following years (Recruits), (b) the midwater trawl index (spawners) and the townet index the following year (Recruits) and (c) the midwater trawl index (spawners) and the midwater trawl index the following year (recruits).

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predictions to decline if smelt abundance peaks at moderate flows and declines at higher flows.

2) <u>Diversions from the spawning and nursery area</u> - Major State and Federal water projects, Pacific Gas and Electric Company power plants, and other industry and local agriculture operations divert huge amounts of water from the Delta during the spawning and nursery period (pages 62 to 73). Many young and adult delta smelt entrained by these diversions are removed from the population. Recent analyses (Stevens et al. MS) indicate that such entrainment losses have caused a severe decline in the Sacramento-San Joaquin Estuary's striped bass population. We used total water exports as measures of diversions.

3) <u>Food supply</u> - Delta smelt feed on zooplankton, especially copepods (pages 4 to 6). Thus, availability of these zooplankton for young smelt potentially could affect their growth, survival and abundance. We used copepod densities (exclusive of nauplii and <u>Sinocalanus</u> <u>doerii</u>) to measure food supply.

4) <u>Reverse flow</u> - Due to water project pumping in the south delta the lower San Joaquin River frequently flows backwards and transports small fish toward the diversions (pages 64 to 67). Moyle and Herbold (1989) suggest that this process is detrimental to delta smelt. We used the number of days of net reverse flow at Jersey Point on the San Joaquin River as our measure of reverse flow.

5) <u>Water temperature</u> - Temperatures may affect delta smelt abundance through effects on growth and mortality. We used average maximum temperatures from the U.S. Geological Survey monitoring station on the Sacramento River at Freeport to provide a general, albeit imperfect, indication of annual temperature conditions.

6) <u>Water transparency</u> - Water transparency may reflect general productivity of the Estuary and/or vulnerability of delta smelt to predation by other fishes. Delta waters have tended to become clearer in recent years (California Fish and Game 1988). We used average Delta-Suisun Bay secchi disc readings from the Bay-Delta project's zooplankton survey as a general indicator of water transparency.

We tested one, two and three variable models for the summer townet survey and fall midwater trawl survey indices using all combinations of these environmental factors (RSQUARE procedure in SAS version 5, 1985). Both abundance indices were evaluated against averages of the environmental factors during the March-June spawning and early nursery period, and the fall midwater trawl index was also evaluated against averages for the July-October late nursery period.

Care must be taken in interpreting results of such regression searches, as even the moderate number of input variables that we used, may lead to some chance relationships which are spurious.

At best, any of the regression models should only be considered as "suggestive" mechanisms which require further testing.

R^2 values indicate that none of the models based on March-June environment explain a satisfactory amount of variability in smelt abundance (Appendices E and F). Of the July-October variables, copepod abundance and water transparency dominated the best models and themselves accounted for almost 70% of the variability in the midwater trawl index (Appendix G). However, despite this apparent association between delta smelt abundance and July-October copepods and water transparency, the importance of these factors should, at best, be considered tentative. Comparisons between the summer townet survey and fall midwater trawl indices suggest that since 1983, at least, delta smelt year class strength has been set before July.

THREATS

Numerous factors potentially threaten the existence of the delta smelt which has probably been at all-time low abundance levels since 1983. Discussion of several of the most obvious factors follows.

Food Supply

Zooplankton abundance in the Estuary has been monitored by the Department's zooplankton monitoring survey since 1972. Zooplankton also have been monitored in the spring since 1984 by the striped bass egg and larva survey. These surveys demonstrate that densities of *E. affinis*, the most common copepod in the delta smelt's diet, were relatively stable prior to 1988. However in 1988, a major decline in *E. affinis* occurred over much of the delta smelt's range (Table 14). This decline coincided with the accidental introduction and population explosion of the clam, *Potamocorbula amurensis*, (pages 78 and 79). The most recent years, 1988 and 1989, provide somewhat ambivalent results regarding the impact of the decline of *E. affinis* on delta smelt. In 1988, the midwater trawl index for delta smelt was at its next to lowest level; however, in 1989, while still very low from a historic perspective, this index rebounded to its highest level since 1983. Nevertheless, the recent decline in this major diet component, still must be considered as a potential threat to the delta smelt's recovery unless other food resources compensate or *E. affinis* recovers to its former abundance.

Table 14. Mean Density of *Eurytemora affinis* per m^3 in the Estuary during May and June.

Year	EC < 1000 uS Zooplankton Survey	EC < 1000 uS Egg and Larva Survey	EC > 1000 uS Zooplankton Survey	EC > 1000 uS Egg and Larva Survey
1972	588		4301	
1973	589		1884	
1974	1017		4980	
1975	378		1378	
1976	369		1794	
1977	370		2232	
1978	639		4172	
1979	262		2390	
1980	176		1466	
1981	258		1410	
1982	533		3246	
1983	806		2673	
1984	128	64	1556	737
1985	51	50	1006	465
1986	485	82	2504	1128
1987	389	--	1437	--
1988	106	48	88	58
1989	---	22	--	29

Low Spawning Stock

Our evaluation of factors regulating delta smelt abundance failed to show that spawning stock abundance had a major influence on delta smelt year class success (pages 52 to 56). Nevertheless, the relatively low fecundity of this species and their planktonic larvae, which undoubtedly incur high rates of mortality, means that annual reproduction must be accomplished by fairly large numbers of fish if the population is to perpetuate itself (Moyle and Herbold 1989). Thus, while the stock abundance may not have been an important factor in the past, present or future low stock levels may inhibit potential for population recovery. Pimm et al. (1988) show that small species with variable populations, like delta smelt, become increasingly vulnerable to extinction as their populations decrease.

Entrainment in Water Diversions

Delta smelt larvae are lost to entrainment in water diversions of the CVP, SWP, and Delta agriculture, the Pacific Gas and Electric Company (PGE) and other industry using water from the Estuary.

The PGE power plant intakes are screened, but these screens are ineffective on larval fish. In 1978-1979, more than 50 million and 16 million smelt larvae (delta smelt & longfin smelt - -

larval smelt are difficult to identify to species and there has not been an attempt to identify them during any of the entrainment monitoring programs) were estimated to have been entrained at PGE's Pittsburg and Contra Costa power plants, respectively (PGE 1981a, 1981b). Also, estimates of impingement of larger delta smelt juveniles on the power plant intake screens were 11,000 fish at Pittsburg and 6,400 fish at Contra Costa.

There is no information available on delta smelt losses in the myriad of delta agriculture diversions which are not screened at all. However, during sampling on 20 days from November 1980-May 1981 and September 1981-March 1982, the delta smelt was the most numerous species entrained in the unscreened Roaring River Slough diversion from Montezuma Slough for water distribution in the Suisun Marsh (Pickard et al. 1982). This sampling, which generally consisted of placing a net over 1 of 8 intake culverts for several hours, captured 5,841 delta smelt.

Substantial entrainment losses also occur at the CVP and SWP despite their intakes being miles from the primary spawning and nursery areas. These losses occur due to the magnitude of the water project diversions, their impact on Delta flow patterns, and the tendency for young delta smelt to be transported and dispersed by river and estuarine currents.

The CVP and SWP pumps are located at the southern edge of the Delta, but pumping rates usually exceed the flow of the San Joaquin River entering the Delta from the south; therefore, most of the water that they export must come from the Sacramento River. Approximately the first 3,500 cfs of flow exported from the Sacramento River crosses the Delta through the CVP's Delta Cross Channel and Georgiana Slough near Walnut Grove and flows to the pumps through natural channels upstream from the mouth of the San Joaquin River. Young smelt that were spawned in the water transport channels or in the Sacramento River upstream from Walnut Grove would be particularly vulnerable to this water management scheme. At higher export rates, water is drawn up the San Joaquin River from its junction with the Sacramento River (Figure 19). Such net upstream flows in the San Joaquin River are typical in all but wet springs, and in the summer and fall of all years. The upstream flows entrain young smelt from the western Delta and carry them to the water project intakes.

Moyle and Herbold (1989) found that high frequencies of reverse flows in the San Joaquin River during spring were always associated with low abundances of delta smelt in Suisun Bay in the fall (Figure 20) while low frequencies of reverse flows sometimes were associated with high abundances of delta smelt. They (MS) also point to a trend of increasing reverse flows in the San Joaquin River, especially during the spawning months.

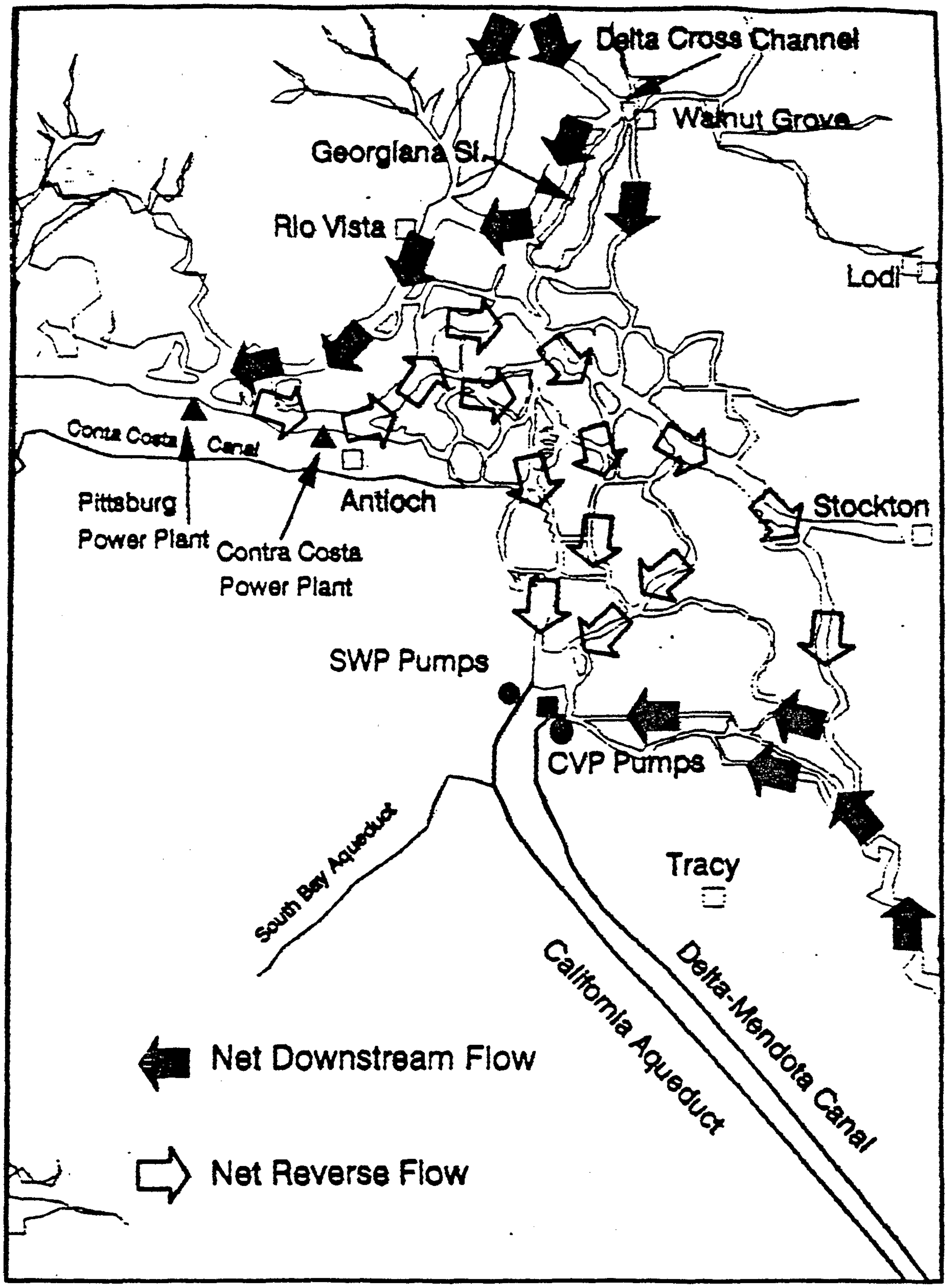

Figure 19. Typical summer flow patterns in the Sacramento-San Joaquin Delta. CVP-SWP export pumping has changed the natural flow patterns. Reverse flows transport many delta smelt from their nursery to the CVP-SWP diversions in the south Delta.

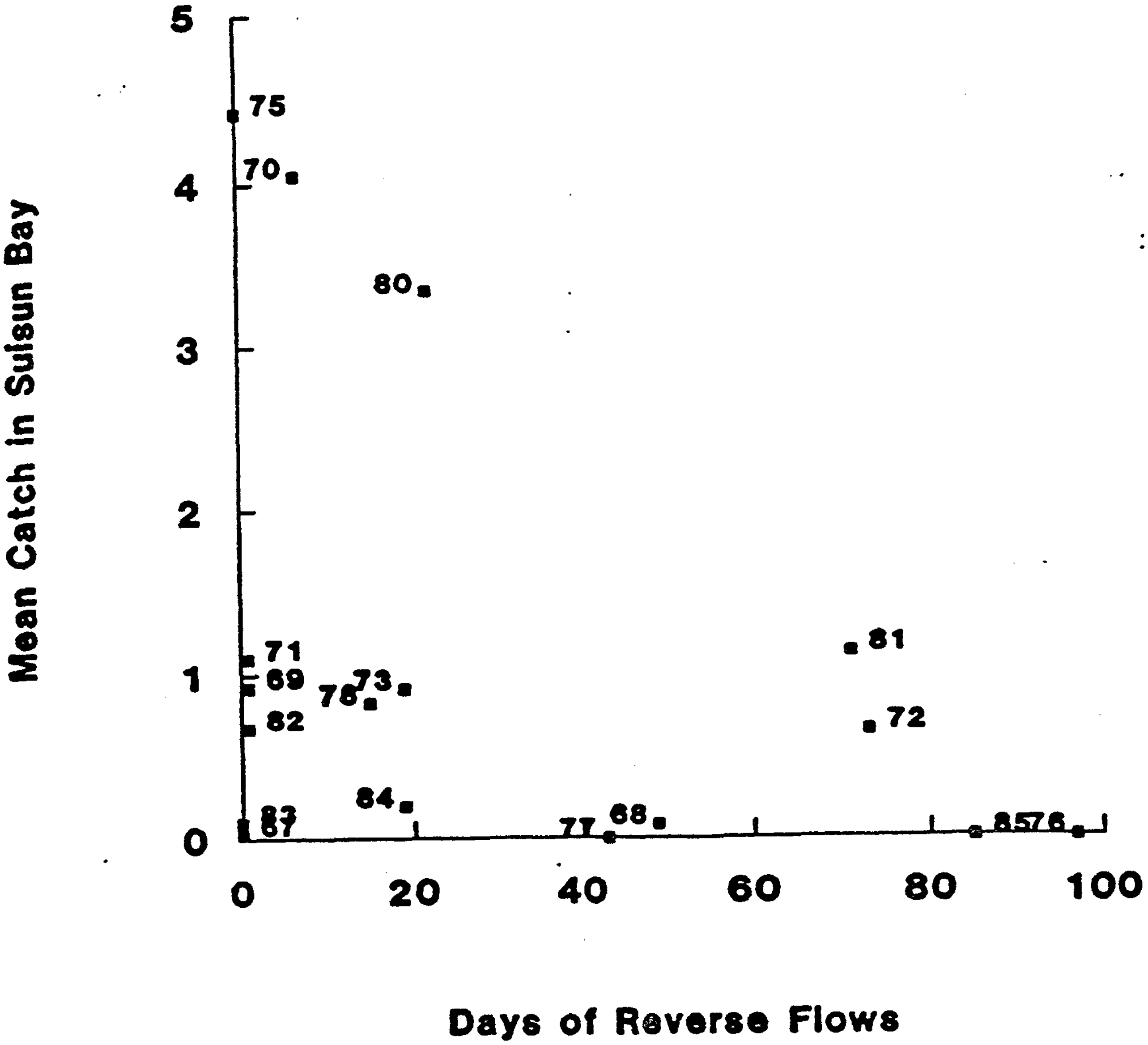

Figure 20. Mean Densities of fall populations of Delta smelt in Suisun Bay vs. numbers of days of reverse flows in the San Joaquin River during March to June. From Moyle and Herbold (1989).

ABUNDANCE VS NUMBER DAYS OF MARCH-JUNE REVERSE FLOW

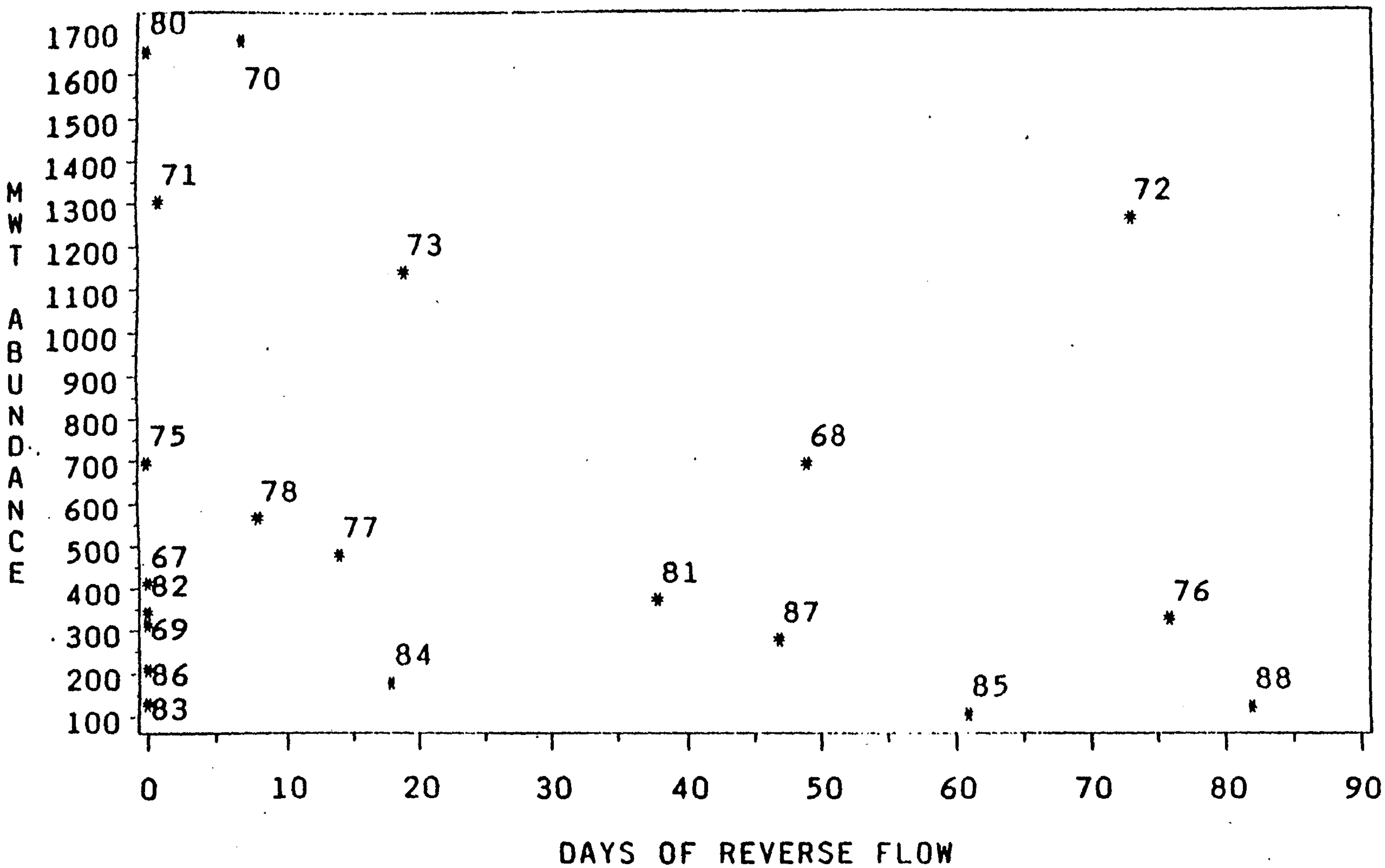

Figure 21. Relationship between fall midwater trawl index of delta smelt abundance and the number of days of reverse flows in the Lower San Joaquin River from March to June.

system. Substantial numbers of the many young delta smelt that are salvaged (pages 31 to 41) also die due to stresses received during the handling and trucking. Others are eaten by larger fish in the SWP's Clifton Court Forebay and near the trash racks at both the CVP and SWP screens. These factors have not been evaluated for delta smelt but are known to be significant detriments to striped bass (DFG 1987).

Delta smelt are most vulnerable to entrainment during spring and summer as shown by the number salvaged per-acre-foot of exports by the SWP (Figure 22). This pattern reflects the late winter-spring spawning season and growth and mortality of young fish. During April and May, abundance of young smelt at the SWP and CVP diversions probably is greater than shown in Figure 22. However, this tendency is not displayed by the salvage estimates because the smelt are so small that they pass through the screens and are not salvaged during the first month or two of life. Also, smaller smelt are not readily identifiable by the technicians responsible for sampling salvaged fish.

The intra-year salvage pattern in 1977-1978 was a notable exception to the typical pattern. Through much of 1977, water exports were reduced, due to a major drought, and while a delta smelt salvage peak occurred in July, the greatest entrainment and salvage of the 1977 year class occurred from December 1977

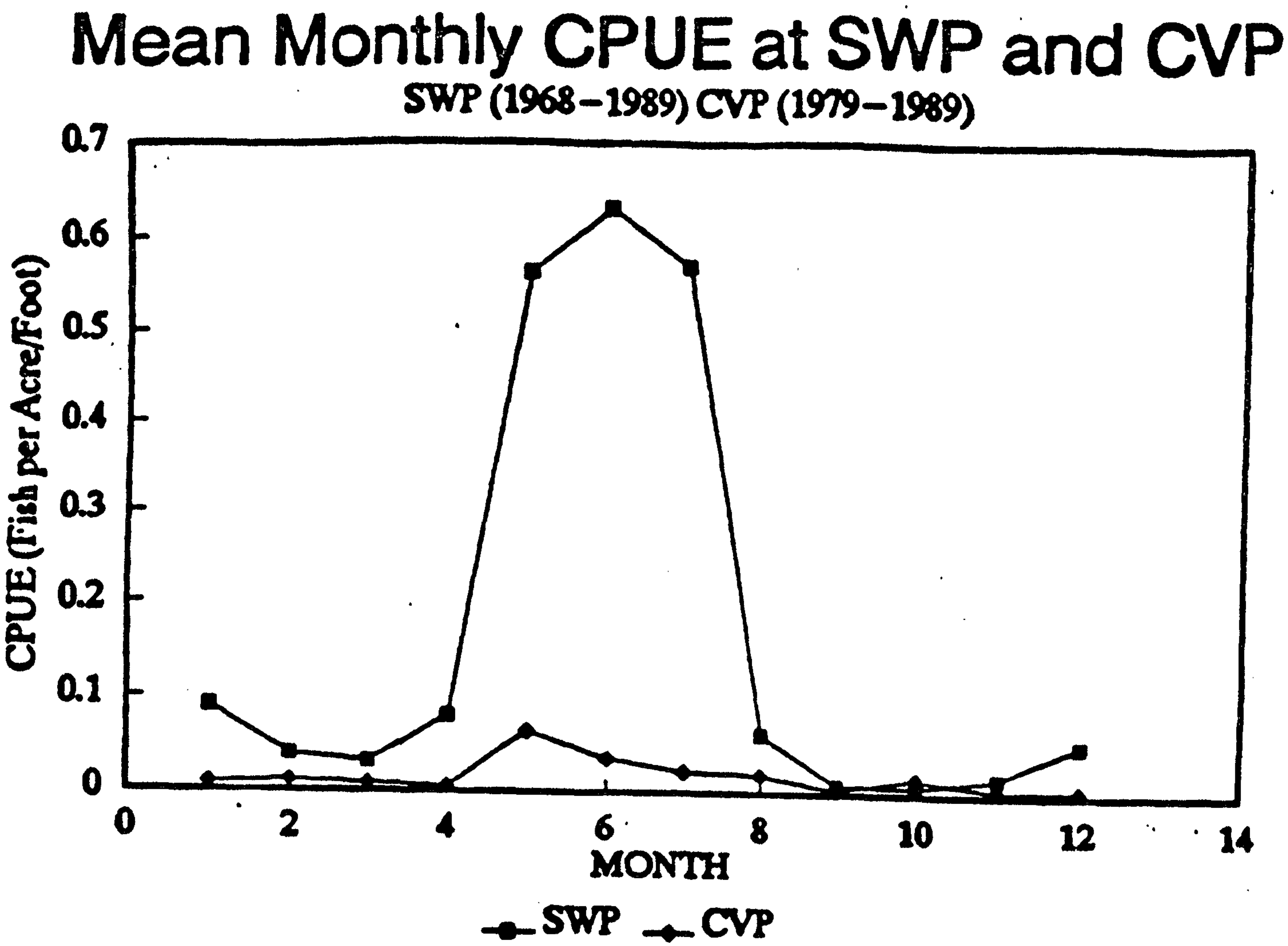

Figure 22. Mean monthly salvage of delta smelt per acre foot of water diverted by the State Water Project and Central Valley Project.

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through February 1978 when water exports increased after the drought broke (Table 15). In fact, the salvage of 134,000 delta smelt at the SWP in January 1978 almost equaled the total for allof 1977 (146,000 fish) and exceeds the annual totals for all subsequent years.

What is the importance of entrainment losses with respect to the population decline of delta smelt? This is unclear. Comparisons of estimated population levels (Table 13) and salvage estimates (Figures 4, 8 and 9) suggest entrainment losses potentially could cause major reductions in delta smelt abundance. The greatest annual salvage, and probably losses, to water project diversions occurred from 1970 to 1976 (Figure 8). Considering that few delta smelt live beyond 1 year, if such entrainment depleted the population, the impact should be noticeable the following year. Yet the population apparently did not crash until 1983, 13 years after 1970, the initial year of record with a major salvage. Also, looking at the salvage data alone, one might hypothesize that the unusual entrainment of maturing adults in 1977-1978 had critically depleted the stock, but again this hypothesis is inconsistent with the population trend depicted by the more comprehensive trawl and townet survey indices.

Nevertheless, delta smelt are ecologically similar to young striped bass which have been severely impacted by water

Table 15. Estimated Salvage of Delta Smelt and Water Exports at the State Water Project diversion in the southern delta, during 1977-1978.

	Month	Delta Smelt Salvage	Exports (thou. acre ft)
1977	Jan	6980	205
	Feb	2430	106
	Mar	1707	97
	Apr	2975	14
	May	3017	68
	Jun	3033	17
	Jul	43489	20
	Aug	6435	15
	Sep	17890	9
	Oct	2528	8
	Nov	350	51
	Dec	55101	224
1978	Jan	134089	365
	Feb	53960	343
	Mar	4217	108
	Apr	130	35
	May	3523	59
	Jun	36289	201
	Jul	1034	211
	Aug	2658	246
	Sep	244	211
	Oct	60	127
	Nov	473	131
	Dec	900	169

diversions (CDFG 1987, Stevens et al. MS.). Delta smelt are vulnerable to diversions throughout their life cycle, particularly in dry years, when they are concentrated in the Delta from which the water is diverted. Thus, even if water diversions were not directly responsible for the delta smelt population decline, their drain on the population may be a significant factor inhibiting recovery.

<u>Toxic Substances</u>

Dr. Moyle's petition points out that the Estuary receives a variety of toxic substances, including agricultural pesticides, heavy metals, and other products of our urbanized society. The effects of these compounds on delta smelt have never been tested, and their effects on fishes in general are poorly understood. Some of these substances are known to occur in the Estuary's fishes at levels that may inhibit their reproduction (Jung et. al 1984) or are sufficient to trigger health warnings (e.g. Mercury in striped bass) regarding human consumption. Also, recent bioassays by the Central Valley Regional Water Quality Control Board (Foe 1989) suggest that water in the Sacramento River is, at times, toxic to larvae of the fathead minnow, a standard EPA test organism . However, the timing of the delta smelt decline is not consistent with the increased, mid-to late-1970s, use of the chemicals thought to cause mortality in these bioassays.

Although there is no direct evidence of delta smelt suffering direct mortality or stress from toxic substances, this factor obviously cannot be eliminated as a potential agent adversely affecting the delta smelt population.

Flows Out of Optimal Range

Moyle and Herbold (1989) point out that the years of the major smelt decline have been characterized by not only unusually dry years with exceptionally low outflows (1987, 1988), but also by unusually wet years with exceptionally high outflows (1983, 1986). They suggest that moderately high flows are most beneficial in that they cause the primary delta smelt nursery area, which is the mixing zone of the Estuary, where outflowing freshwater meets incoming tidal water, to be located in Suisun Bay. Moyle and Herbold developed a complex analysis which suggests high productivity (as reflected in phytoplankton and zooplankton abundance) in the mixing zone is one of the strongest determinants of delta smelt abundance. This high productivity is associated with the establishment of the mixing zone in the shallow water of Suisun Bay. Thus, they suggest moderately high outflows are important in that food becomes more available for larval smelt than when outflows are extremely high or too low. Higher and lower outflows place the mixing zone and nursery too far downstream or upstream. Low outflows also are detriments in that the delta smelt population concentrates in the Delta portion of the Estuary where they are most vulnerable to becoming entrained in water diversions.

Moyle and Herbold's thesis is logical; however, it is not entirely supported by the abundance indices that we have described. For example in 1972, the fall midwater trawl index was quite high despite low outflows and a levee break on Andrus Island drawing the mixing zone well into the Delta during June. Also, relatively high summer townet survey indices suggest early survival of delta smelt larvae was high during the drought of 1976 and 1977. Subsequent survival of these year classes appeared to be low, however. Furthermore, our multiple regression analysis (pages 56 to 59) did not indicate that delta smelt abundance is controlled by delta outflows.

Figure 23 illustrates the best relationship (selected from R^2 values after running all possible 2 consecutive monthly subsets from February to June) between the fall midwater trawl abundance index, delta outflow, and delta outflow^2. As explained previously, the outflow^2 term allows the regression predictions to decline if smelt abundance peaks at moderate flows and declines at high flows. Again, there is no evidence that outflow has had major effects on delta smelt abundance.

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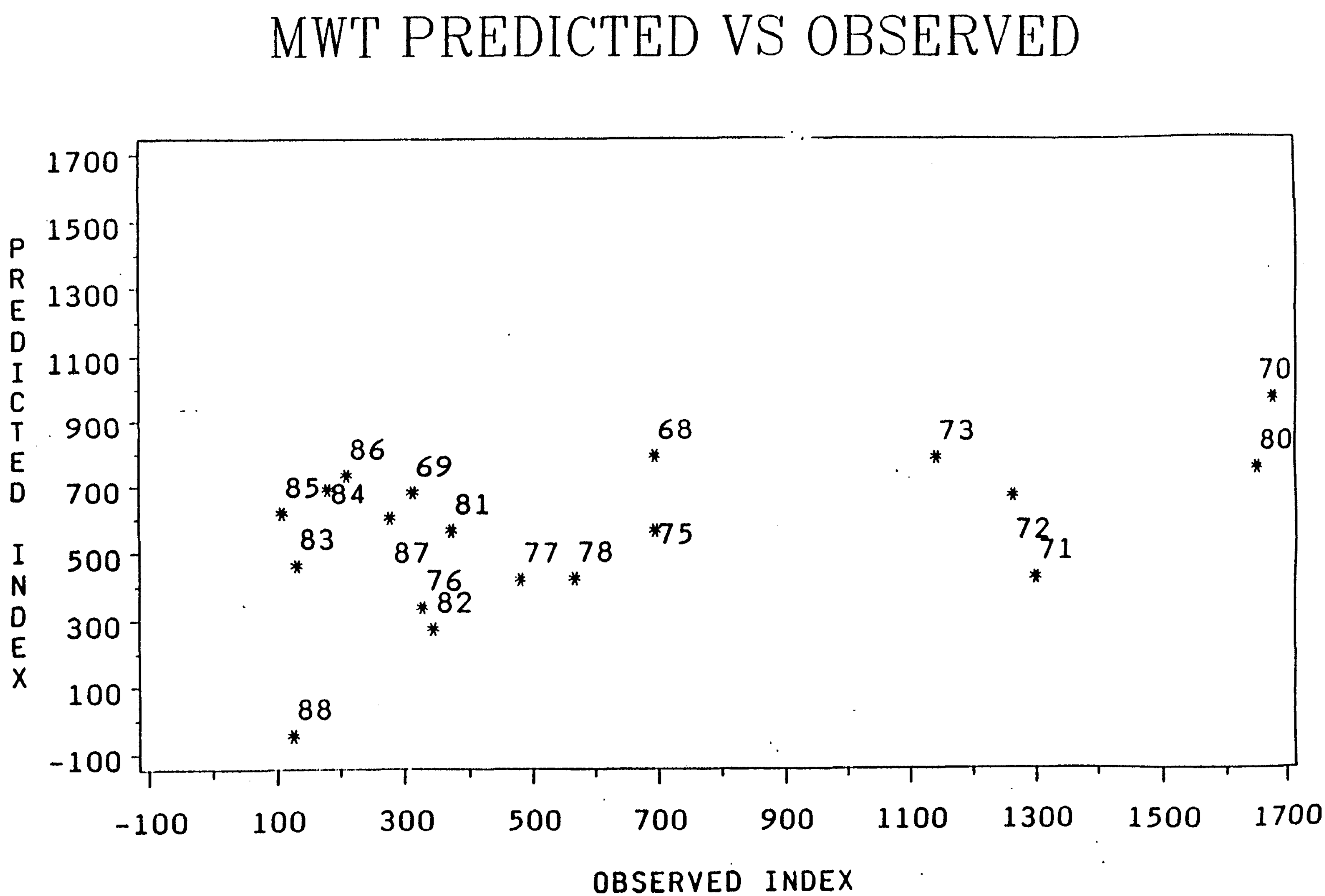

Figure 23. Relationship of midwater trawl observed abundance indices and those predicted by the equation: -2635.7 + 1347.26 (Log_{10} mean February-March Delta outflow) -146.9 (Log_{10} mean March-April Delta outflow)^2. R^2 = 0.22.

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Notably, the recent series of very weak year classes began in 1983 which had a record sustained period of high spring outflows. That year, a substantial portion of the year class likely was washed far beyond Suisun Bay and perhaps entirely out of the Estuary.

Genetic Dilution

The closely related wagasaki, or Japanese smelt, was introduced in 1959 by the Department of Fish and Game into six California lakes and reservoirs: Dodge Reservoir (Lassen County), Dwinnell Reservoir (Siskiyou County), Freshwater Lagoon (Humboldt County), Spaulding Reservoir (Nevada County), Sly Park Reservoir (El Dorado County) and Big Bear Lake (San Bernardino County) (Wales 1962). They have subsequently been introduced into other reservoirs, including Shastina Reservoir (Siskiyou County) and Almanor Reservoir (Plumas County) (Moyle 1974, Moyle and Herbold 1989). Although the status of the introduced populations is uncertain, the potential exists for this fish to appear anywhere in the lower Klamath River system, the Sacramento River system, and possibly other systems as well (Moyle 1974). Wagasaki were collected from Folsom Reservoir (El Dorado County) by Department biologists in 1989 (D.P. Lee, Associate Fishery Biologist, CDFG, pers. comm.).

The wagasaki may hybridize with Delta smelt, but whether they have is not known, nor is it known if such hybridization could have a negative effect on the fitness of the Delta smelt. Thus, the threat of loss of genetic integrity or the possibility that the wagasaki could displace the Delta smelt completely through introgression or direct competition (Moyle and Herbold 1989) should be considered as speculative.

Exotic Species

Since the early 1970s, several exotic species, including both fish and invertebrates, have been accidentally introduced into the Sacramento-San Joaquin Estuary and become firmly established. A fish, the inland silverside (*Menidia berylina*), similar in size and food requirements to delta smelt, entered the Estuary in 1975 (Meinz and Mecum 1977) after flood flows transported it to the Delta from Clear Lake where it was intentionally, but illegally, introduced in 1967 (Fisher 1973). The invertebrate introductions have occurred through the discharge of organisms carried in ballast water of ships. The exotic invertebrates have included, since 1978, four species of zooplankton, all copepods (*Sinocalanus doerii*, *Limnoithona sinensis*, *Oithona davisae*, and *Pseudodiaptomus forbesi*); an amphipod (*Lagunogammarus sp.*); and a clam (*P. amurensis*). All of these invertebrates are of Asian origin. Some of these exotic species invasions and their population explosions occurred before, others occurred after, but none coincide with the delta smelt decline.

Of the exotic copepods, S. doerii (established 1978) and P. forbesi (established 1986) have become particularly abundant. S. doerii apparently is rarely eaten by delta smelt; however, P. forbesi is now a major part of their diet. Laboratory experiments (Meng and Orsi, University of California, Davis and CDFG, respectively) have shown that larval striped bass readily take P. forbesi, but have difficulty capturing S. doerii. Apparently, the same is true for delta smelt. Potentially, the establishment of P. forbesi should compensate for the substantial decline in E. affinis which occurred during 1988 and 1989. However, since P. forbesi's annual cycle is such that it does not become abundant until summer, it is not readily available for the initial feeding of young smelt during the spring. Circumstantial evidence, from field monitoring and some sketchy laboratory experiments, suggests that filtering by the clam, P. amurensis, may have caused the decline in E. affinis which, historically, was available to delta smelt during their early nursery period. While this decline in E. affinis occurred after the decline in delta smelt, its near absence, possibly caused by the exotic, P. amurensis, may inhibit the smelt's recovery.

Disease and Parasites

Diseases and parasites of delta smelt have never been studied; thus, there is no evidence concerning their role in the population decline. General studies on parasites of Delta fishes, however, have found numerous protozoans, worms (trematodes, cestodes, nematodes, etc.) and crustaceans which have affected at least 28 species of fish (Edwards and Nahhas 1968, Hensley and Nahhas 1975). Striped bass in the Delta are more heavily infested with parasites than Atlantic coast striped bass, perhaps indicating that the Delta environment may be degraded by toxicants or pollutants to the point that resistance to parasites in resident fishes is weakened (CDFG 1989). Also, widespread sightings of dead fish suggest that, in some years, disease outbreaks have caused mass mortalities of carp (Cyprinus carpio) and white catfish (Ictalurus catus) in California's Central Valley including the Delta. If disease or parasites are important or should they become important, they certainly could prevent the recovery of delta smelt from current population levels.

Competition and Predation

Delta smelt evolved with native predators such as squawfish (Ptychocheilus grandis), Sacramento perch (Archoplites interruptus), and steelhead (Oncorhynchus mykiss); however, predation by these species, none of which is currently abundant in the Estuary, is unlikely to be responsible for the relatively recent decline observed in Delta smelt. Striped bass, which were introduced in 1879, have been the most abundant predator (adults and sub-adults) and competitor (young) in the portion of the Estuary inhabited by Delta smelt, but striped bass also have suffered a serious decline which began in the 1970s and preceded the decline in delta smelt. Also, abundance indices for several other potential predators or competitors did not exhibit increases that could account for reduced delta smelt abundance (Figure 24). In fact, several of those potential competitors or predators--longfin smelt, threadfin shad and white catfish--also show signs of population erosion approximately coinciding with, or, in the case of white catfish, preceding the decline of delta smelt.

In essence, there just has not been a consistent increase in the abundance of any potential predator or competitor that could account for the decline of delta smelt.

Drs. Moyle and Herbold (1989) suggest that the Department's effort to enhance the Sacramento-San Joaquin striped bass population through the stocking of hatchery-reared fish could cause excessive predation on delta smelt. Striped bass are highly pisciverous (eat other fish); however, comprehensive striped bass food habit studies (Stevens 1966, Thomas 1967)

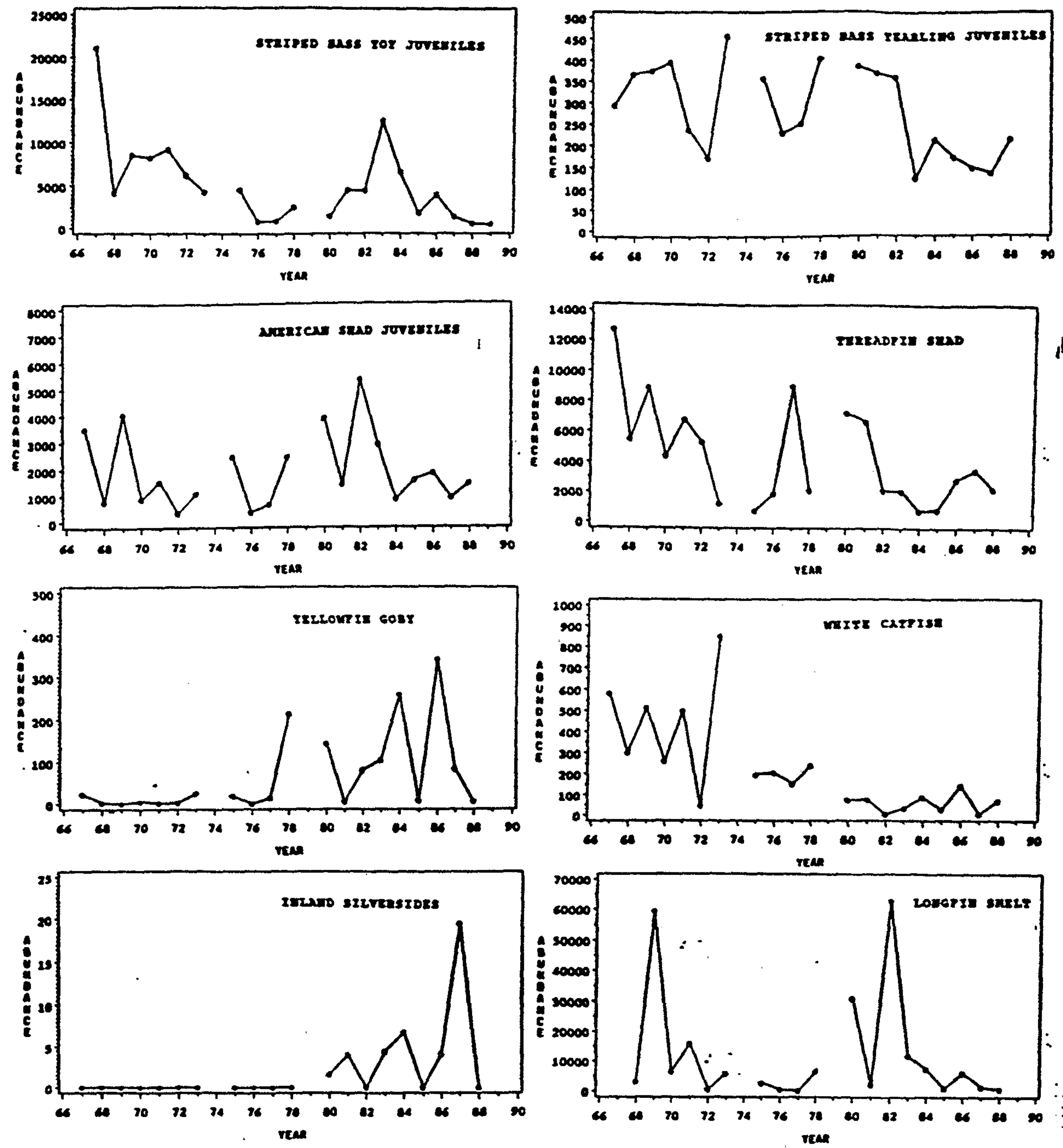

Figure 24. Trends in midwater trawl abundance indices of potential competitors or predators of delta smelt. These abundances have either decreased or been stable coincident with the period of decline in Delta smelt except for the yellowfin goby which generally has been more abundant. There were no trawl surveys in 1974 and 1979.

indicated that, while delta smelt were occasionally consumed, they were not a significant prey of striped bass even in the early 1960s when delta smelt and striped bass were both much more abundant. Thomas (1967) notes that several potential prey species, including delta smelt, were less abundant in the striped bass diet than expected based on their abundance in the environment. Factors which reduce the availability of delta smelt and certain other species to striped bass are not understood.

Thus, while competition and predation cannot be ruled out as threats to delta smelt, the available evidence suggests that they are not a major threat.

CONCLUSIONS

We have examined several measures of delta smelt abundance; all indicate that the population has declined, although these measures are not consistent in their depiction of the timing and magnitude of the decline. The best measures, based on the summer townet and fall midwater trawl surveys, indicate that delta smelt abundance consistently has been lower since 1983 than in previous years. Based on the midwater trawl survey, the average population since 1983 (index of 175) has only been about one-fifth of the average population level (index of 861) from 1967 to 1982, and one-tenth of the peak level (index of 1840) in 1980. Delta smelt abundance has been highly variable over the period of record. Our evaluation of factors potentially affecting delta smelt abundance did not point strongly to any particular cause of this variability or the sustained population decline since 1983. However, failure to identify factors regulating the population does not mean the tested factors are not important. Such failure may simply reflect sampling associated variability in our measures of delta smelt abundance and/or the environment.

The Fish and Game Commission is guided by the State Endangered Species Act and the guidelines promulgated under this Act in determining whether a species may be properly listed as endangered or threatened. Section 670.1(b) of Title 14 of the California Code of Regulations sets forth the listing criteria. Under this section, the Commission may list a species if it finds that its continued existence is in serious danger, or is threatened by any of the following factors.

- Present or threatened modification or destruction of its habitat;
- overexploitation;
- predation;
- competition;

- disease; or
- other natural occurrences or human-related activities.

To meet the State Endangered Species Act's definition of "endangered", a species must be:

(1) a native species or subspecies;

(2) a bird, mammal, fish, amphibian, reptile or plant;

(3) in serious danger of becoming extinct throughout all, or a significant portion, of its range;

(4) affected by loss of habitat, change in habitat, overexploitation, predation, competition, or disease (Cal. Fish and Game Code Sec. 2062).

A "threatened" species is a species which is "likely to become an endangered species in the foreseeable future" in the absence of the special protection provided by the Act. (Sec. 2067). The Fish and Game Code (Sec. 2072.3) lists additional factors relevant to a determination that a species is threatened or endangered:

- population trend;
- range;
- distribution;
- abundance;
- life history;

- ability to survive and reproduce;
- degree and immediacy of threat;
- existing management efforts;
- type of habitat.

Dr. Moyle's petition declares: "The Delta smelt fits the definition of an endangered species as it is in danger of extinction throughout its entire limited range. It is vulnerable to extinction because (1) it is short-lived, (2) it has relatively low fecundity, (3) it is a planktivore throughout its life cycle, and (4) it is confined to the upper Sacramento-San Joaquin estuary." Our analysis indicates that declarations (1)-(4) are true. Additionally, introductions of exotic organisms have altered the delta smelt's food supply, and water projects have adversely modified the delta smelt's habitat, distribution and probably abundance within the Estuary. While our analysis failed to determine the specific relationships between these threats and the smelt population, that is not crucial to determining whether delta smelt should be listed as threatened or endangered.

Major adverse habitat modifications include effects of changes in the character and position of the salinity gradient and exploitation through entrainment in diversions. Such population threats are likely to worsen or, at best, remain stable (Table 16). Trends in abundance of other species, such as striped bass,

Table 16. Probable Trend in Delta Smelt Population Threats. W = worse, S = Stable

Threat	Trend
Inadequate Food Supply	S
Inadequate spawning stock	S or W
Entrainment Losses	W
Toxicity	?
Delta outflows	W
Genetic dilution	S
Exotic introductions	S (if ship ballast discharges are controlled), W (if ship ballast discharges are not controlled)
Disease and parasites	S or W

also point toward a general degradation of the delta smelt's habitat.

Thus, the delta smelt population trend, certain life history attributes, and environmental threats tend to support "listing". The most relevant issue, however, is whether the population is low enough that it is in danger of extinction. The scientific information is insufficient to make that determination. Unfortunately, it is a very complicated scientific determination, and no scientific study which we might implement will provide a conclusive answer in the next few years. Meanwhile the population might become extinct.

The Department of Fish and Game believes that the relatively stable, albeit low, population is not in imminent danger of extinction. One factor supporting this contention is that the population has historically rebounded quickly from levels nearly as low as present ones. While we cannot be certain that such rebounds will not happen again, the persistent low populations since 1983, the nature of the delta smelt's life history and distribution, and increasing threats to its habitat lead us to conclude that the delta smelt may well "become an endangered species in the forseeable future". Hence, based on the best scientific information available (Section 2074.6 CESA), the

Department believes that the most prudent action is to list the delta smelt as a Threatened Species.

RECOMMENDATIONS

Petitioned Action

1. The Commission should find that the petitioned action that is warranted is for the status of State Threatened.
2. The Commission should publish notice of its intent to amend Title 14 CCR 670.5 to add the delta smelt (*Hypomesus transpacificus*) to its list of Threatened and Endangered Species.

Recovery and Management Actions

The Department's objective is the protection of a sufficient number of delta smelt to insure their long-term survival in their native habitat and range. In order to achieve recovery, the population must be protected, monitored, and shown to be self-sustaining. Annual monitoring and evaluation should be increased after input from interested parties. Recovery goals and reclassification criteria need to be established. When recovery goals have been met, the Department will make recommendations to the Commission regarding delisting this species.

The following actions have potential to achieve management and recovery objectives.

1. Improve species identification and fish handling procedures at the existing State and Federal Water Project diversions from the Delta. Such actions could reduce present entrainment losses to these major diversions.

2. Modify pumping strategies at the State and Federal Water project diversions to reduce entrainment losses during periods when delta smelt are most abundant.

3. Increase spring and summer delta outflows to maintain the entrapment zone and major delta smelt nursery in the Suisun Bay region where food supplies are greater than in the Delta and exposure to diversions is minimal.

4. Support regulations restricting ship ballast water discharges to eliminate or minimize new introductions of potentially harmful exotic species. S 2244 and HR 4214 currently being considered by the U.S. Congress would create such regulations.

5. Evaluate losses to agricultural diversions in the Delta. Screening these diversions probably would reduce entrainment and losses to local crop irrigation.

6. Remove water project diversions from the Delta. Moving the diversion intakes to the Sacramento River upstream from the major nursery area would do this and also provide benefits to other species which formerly made more use of the Delta.

7. Consider developing pond culture techniques for the purpose of creating "refuge" populations.

__Alternatives to the Petititioned Action__

If the Commission should choose not to list the Delta smelt, it is our opinion that this fish would be deprived of protection provided through recognition and formal consultation available to a listed species. When a species is listed as Threatened or Endangered, a higher degree of urgency is mandated, and protection and recovery receives more attention from the Department and other agencies than does a non-listed species.

In the absence of listing, it still would be possible to devise a management plan for this species. However, this Departmental status review indicates that the future existence of this species is already seriously threatened. Despite good intentions on the part of the Department and the Commission, promises of management and protection for a non-listed species do not have the weight of law behind them, and thus seldom receive high priority in the eyes of other agencies. Without the benefits of listing and the cooperation of other agencies in preservation and recovery actions, the species could decline further until the population is no longer viable, and is no longer able to exist in perpetuity. Eventually, extinction could occur.

Although the petitioner has requested listing of the Delta smelt as Endangered, the Department has made the recommendation and the Commission has the option to list this fish as Threatened instead. Under this option, the Delta smelt would receive the same special consideration and protection under CESA and the California Environmental Quality Act (CEQA) as if it were listed as Endangered. This Departmental status review indicates that the continued existence of the Delta smelt is seriously threatened throughout its range, and that this alternative is appropriate.

PROTECTION AFFORDED BY LISTING

If listed, the Delta smelt will receive protection from take during development activities subject to CEQA and will be subject to formal consultation requirements under CESA. The species will also be eligible for the allocation of resources by government agencies to provide protection and recovery. During the CEQA environmental review process, listed species receive special consideration, and protection and mitigation measures can be implemented as terms of project approval. Species that are not listed do not readily receive protection. The status of listing provides a species with recognition by lead agencies and the public, and significantly greater consideration is given to the Department's recommendations resulting from project environmental review.

Listing this species increases the likelihood that State and Federal land and resource management agencies will allocate funds and personnel for protection and recovery actions that benefit the Delta smelt. With limited funding and a growing list of Threatened and Endangered species, priority has been and will continue to be given to species that are listed. Those that are not listed, although considered to be of concern, are rarely given serious consideration under these circumstances.

ECONOMIC CONSIDERATIONS

The Department is not required to prepare an analysis of economic impacts per CESA Section 2074.6. The Department is to provide a report to the Commission "based upon the best scientific information available to the Department, which indicates whether the petitioned action is warranted, which includes a preliminary identification of the habitat that may be essential to continued existence of the species, and which recommends management activities and other recommendations for recovery of the species".

C-048696

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NEWSPAPERS WHICH PUBLISHED THE DELTA SMELT LEGAL NOTICE

Sacramento Bee
PO Box 15779
Sacramento, CA 95852

Fairfield Daily Republic
PO Box 47
Fairfield, CA 94533

San Francisco Chronicle
901 Mission Street
San Francisco, CA 94103

Contra Costa Times
PO Box 5088
Walnut Creek, CA 94596

Beginning June 22, 1990 the Department of Fish and Game circulated a draft report entitled **"Report to the Fish and Game Commission: A Status Review of the Delta Smelt (*Hypomesus transpacificus*) in California."** This report was prepared in accordance with Section 2074.6 of the Fish and Game Code. The draft report was provided to the following individuals and organizations that responded to a November 27, 1989 public notice to other individuals and organizations that the Department identified as interested parties and to the general public. The distribution of the draft report provided an opportunity for public review and comment before the Department submitted a final report to the Fish and Game Commission and ensured that the Department had access to the best scientific information.

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NOTICE IS FURTHER GIVEN that any species above proposed to be added to the State list as endangered or threatened is a "candidate species" pursuant to Section 2074.2 (FGC) and, pursuant to Section 2085 (FGC), may not be taken or possessed except as provided by Section 2080, et seq. of the FGC or other applicable statutes.

Susan A Cochrane

Susan A. Cochrane, Chief
Natural Heritage Division

C-048707

(916) 324-8348

June 22, 1990

To Whom It May Concern:

The enclosed draft report represents the Department of Fish and Game's analysis and response to a petition to list the Delta Smelt as an endangered species. The Department has determined that the Delta Smelt meets criteria set forth in the California Endangered Species Act of 1984 for listing as a threatened species. This draft report is being provided to all individuals and organizations that responded to our public notices earlier in the review process. We are providing another opportunity for the public to comment on this matter before the Department transmits a final report to the Fish and Game Commission for receipt at their August 3, 1990 meeting. Your comments must reach this office by July 18, 1990 to be included in our final status report. The Commission will conduct a hearing on the Departments recommendation and take public testimony at their August 31, 1990 meeting in Sacramento.

Thank you for your interest in this matter.

Sincerely,

Susan A. Cochrane, Chief
Natural Heritagae Division

CALIFORNIA DEPARTMENT OF FISH AND GAME
NOTICE OF AVAILABILITY OF REPORTS

NOTICE IS HEREBY GIVEN that a draft report prepared by the Department of Fish and Game, pursuant to Section 2074.6 of the Fish and Game Code, in response to a petition to list the delta smelt (Hypomesus transpacificus) as an endangered species, is available for review and comment at the Natural Heritage Division Office, 1220 "S" Street, Sacramento, CA 95814, phone (916) 324-0561.

The Fish and Game Commission will receive the Department's final report at their August 3, 1990 meeting. The Commission will conduct a hearing on the Department's recommendation and take public testimony at their August 31, 1990 meeting in Sacramento.

Department of Fish and Game
Inland Fisheries Division

Robert R. Rawstron

June 29, 1990

Robert R. Rawstron, Chief

C-048709

Appendix B. Summary of Public Comments on Draft Status Review

A draft of this report was released on June 22 for public comment. The cover letter from Susan A. Cochrane, Chief Natural Heritage Division specified that comments must reach the Department by July 18, 1990 to be included in the final status report. Comments were received from the following individuals and organizations: 1) State Water Contractors (SWC), 2) McDonough, Holland and Allen, attorneys for Central Valley Project Water Association (CVPWA), 3) Downey, Brand, Seymour, and Rohwer (DBSR), attorneys representing more than twelve reclamation districts which siphon or pump water from delta channels, 4) California Central Valley Flood Control Association (CCVFCA), 5) The Planning and Conservation League (PCL), 6) Drs. Bruce Herbold and Peter Moyle (HM), 7) The Department of Water Resources (DWR), and 8) Dr. Dallas Weaver, Scientific Hatcheries (DW).

Concerns were expressed in the following general areas:

- adequacy of available information for purposes of depicting the delta smelt population trend and status (SWC, CVPWA),

- verification of the taxonomic status of the species (SWC, CVPWA),

C-048710

- adequacy of data regarding the diet of delta smelt (SWC, CVPWA),

- resolution on the timing and distribution of spawning, mechanisms of larval transport, and reproductive potential (SWC, CVPWA),

- resolution on distribution within the Estuary (SWC, CVPWA),

- weak linkage between abundance and factors potentially controlling abundance (SWC, CVPWA, DWR),

- need for stronger technical foundation in support of listing and management recommendations (SWC, CVPWA, DWR),

- increased cost of water associated with screening agricultural diversions and the question of screen effectiveness on fish as small as delta smelt (DSBR, CCVFCA, DWR),

- predation by birds should be considered as a potential mortality factor (DW),

- changes in carbon-nitrogen-phosphorus ratios due to sewage treatment may affect productivity of the food chain (DW),

- water diversion is the cause of the situation and consideration should be given to upgrading the listing to Endangered (PCL, HM).

We believe that some of these concerns have merit. In some cases they are consistent with statements in our draft text and in some cases we have modified the present text in response. Conversely, we also disagree with some of the comments and stand by our original analysis. Taken individually or collectively, the technical comments do not change conclusions about the status of the smelt population or the factors affecting it.

The SWC, CVPWA and DWR point to apparent discrepancies between certain conclusions reached in the report and the recommendations. The Department believes that those apparent discrepancies are due to the draft report's failure to explain adequately the logical basis for recommendations and that there is no discrepancy between conclusions about the status of the smelt population and the recommendations.

The most essential conclusions are that the Delta smelt population fluctuated widely in abundance from 1959 through 1982, but has been consistently at or below previous minimum levels since 1983; the causes for their low abundance are uncertain, although a number of impacts and likely threats are evident; and scientific information is insufficient to determine the minimum viable population size. In this regard, despite their technical comments, the SWC concede that there is "ample evidence to suggest that delta smelt are at a relatively low level of abundance and therefore represent a species of concern" (p. 9 Attachment 1, July 18, 1990 letter from George Baumli to Susan Cochrane), and DWR states that "it is clear that the population has been low and relatively stable for the past several years" (July 19, 1990 memorandum from Robert G. Potter to Susan Cochrane). The central issue, therefore, is whether the delta smelt is truly likely to become an endangered species in the foreseeable future and deserving of Threatened status.

The Department disagrees with PCL and HM and agrees with the SWC, CVPWA and DWR that based on available evidence there is a measure of uncertainty regarding endangerment (page 88, this report). We believe that at least three alternative conclusions about the population's status merit careful consideration. These are:

1. Some set of circumstances has caused the recent consistent low abundance levels but not permanently reduced habitat carrying capacity, so recovery may occur spontaneously.

2. Habitat degradation has permanently reduced this population to a low but stable level.

3. Habitat degradation has caused the population to fall to a low, temporarily stable level, but increasing habitat stress is likely to cause the population to decrease further.

The first alternative would clearly not warrant listing the smelt. The second would warrant listing only if the present population level is close to the minimum viable population size. At first glance, that seems unlikely considering the rapid historical increases from similar levels, but subsequent habitat degradation may have affected population viability. The third could warrant listing as threatened, depending on the likely consequences of a further decline.

While none of the alternatives can be ruled out, the Department concluded that the third is sufficiently likely and warrants listing the smelt as threatened. Specific supporting reasons are:

1. The general degradation of phytoplankton, zooplankton and several species of fish including delta smelt, in the Delta and Suisun Bay.

2. The association of some of these changes with water development, with reverse flows and losses in project diversions causing particularly important effects.

3. Those water development effects will increase unless specific mitigative actions are taken.

4. The rapid changes associated with accidental introductions of invertebrates which probably haven't stabilized yet.

5. The vulnerability of delta smelt to extinction due to their limited distribution, and life history characteristics.

6. The uncertainty about factors controlling the abundance of smelt, which leads to an inability to conclude that smelt are unlikely to be harmed by further changes.

7. Each additional year of depressed populations makes it more difficult to rationalize the situation as reflecting temporary habitat degradation.

The SWC, CVPWA and DWR all advocate comprehensive studies as an alternative to listing. The Department recommends that such studies should be part of the recovery and management actions, rather than a substitute for listing. The Department's reasons are:

1. The status of this resource is much better defined by past programs than the SWC and CVPWA believe it is.

2. Management actions are warranted now due to risks posed by continuing environmental changes, and

3. Experience indicates that conclusive results will not be achieved quickly by proposed studies.

In addition to studies, DWR advanced two management recommendations as follows:

- The species list for the 1986 DFG-DWR agreement to offset DWR's direct Delta pumping impacts be expanded from striped bass, chinook salmon, and steelhead, to include Delta smelt. This action would result in funds being made available to develop projects to offset DWR's entrainment losses.

- The present DFG/DWR/USBR negotiations to develop an agreement to offset CVP/SWP indirect Delta impacts be expanded to include Delta smelt. (The negotiations presently focus on striped bass and chinook salmon).

The Department considers these helpful, but not specific enough. They would logically lead to consideration of the specific measures included in our recommendations. The lack of certainty as to the cause of the decline creates uncertainty as to the measures which should be undertaken to increase the population. The Department has chosen to recommend a series of habitat improvement measures related to the life history of smelt. The Department is confident that the recommended measures would improve habitat quality in the Delta and Suisun Bay and have a high probability of increasing smelt abundance.

Proposals to modify CVP/SWP pumping strategies to reduce entrainment losses, and to augment Delta outflow, have drawn specific criticism, considering the lack of strong relationships between entrainment losses, outflow and smelt abundance found during the analysis. While strong, long-term relationships do not exist, the Department considers the drain of present water diversions on the delta smelt population to be a significant factor inhibiting their recovery and flow augmentation is worth considering, at least as a vehicle to reduce such losses. Greater flows would reduce these losses by transporting the smelt population downstream away from the diversions.

In response to concerns about screening delta agricultural diversions we have modified our draft recommendation to include an initial evaluation phase.

Appendix C. Delta smelt abundance indices for the townet survey for the years 1959-1965 and 1969-1989

Year	Survey 1	Survey 2	Mean
1959	0.1	22.2	11.1
1960	21.6	26.0	23.8
1961	18.9	17.0	18.0
1962	20.3	26.5	23.5
1963	1.3	2.1	1.7
1964	11.4	36.4	23.9
1965	6.4	5.3	5.9
1969	3.7	1.2	2.7
1970	20.3	43.4	31.9
1971	8.9	15.8	12.4
1972	9.2	12.8	11.0
1973	21.5	21.0	21.2
1974	12.0	13.8	13.0
1975	7.0	16.7	11.9
1976	63.0	38.2	50.6
1977	12.5	37.1	24.8
1978	23.0	102.0	62.5
1979	6.4	19.9	13.2
1980	14.7	16.9	15.8
1981	19.1	20.5	19.9
1982	7.0	14.3	10.6
1983	3.3	2.5	2.9
1984	1.3	1.2	1.3
1985	0.8	0.9	0.9
1986	7.4	8.3	7.8
1987	0.4	2.4	1.4
1988	0.5	1.8	1.2
1989	3.6	0.8	2.2

Appendix D. Weight Factors used for Midwater Trawl Survey Data.

Area	Midwater Trawl Stations	Acre ft.
1	336-339	81,000
2	320	28,000
3	321-326	113,000
4	327-329	65,000
5	330-335	122,000
6	317-319	59,000
7	312-316	102,000
8	303-311	185,000
9	301-302	30,000
10	340	48,000
11	401-402,404-408	160,000
12	409-419	140,000
13	501-520	180,000
14	601-606,608	50,000
15	702-711	120,000
16	801-815	140,000
17	901-915,918,919	200,000

Appendix E. Regression search of potential effects of March to June environmental variables on the summer townet survey abundance index for delta smelt. See appendix H for Key to variable names.

N=16 REGRESSION MODELS FOR DEPENDENT VARIABLE: TNS_IND MODEL: MODEL1

NUMBER IN MODEL	R-SQUARE	ADJUSTED R-SQUARE	SSE	C(P)	VARIABLES IN MODEL
1	0.00245546	-.06879772	4445.9463	0.126004	MR_J_FT
1	0.00918957	-.06158261	4415.9331	0.0441457	DAY_REVS
1	0.01253711	-.05799595	4401.0135	0.00345339	LMJN_OT2
1	0.01280421	-.05770977	4399.8230	.000206564	LMJN_OUT
1	0.07543021	0.00938952	4120.7058	-0.761066	MJN_EXP
1	0.07861687	0.01280379	4106.5033	-0.799802	MJN_COP
1	0.18925268	0.13134216	3613.4116	-2.1447	MJN_WT
2	0.00918957	-.14324280	4415.9331	2.044146	MR_J_FT DAY_REVS
2	0.01286260	-.13900470	4399.5628	1.999497	LMJN_OT2 DAY_REVS
2	0.01312179	-.13870563	4398.4076	1.996346	LMJN_OUT DAY_REVS
2	0.01320068	-.13861460	4398.0560	1.995387	LMJN_OUT LMJN_OT2
2	0.01612688	-.13523821	4385.0143	1.959817	LMJN_OT2 MR_J_FT
2	0.01624085	-.13510671	4384.5063	1.958431	LMJN_OUT MR_J_FT
2	0.07582923	-.06635089	4118.9275	1.234084	MR_J_FT MJN_EXP
2	0.07861957	-.06313127	4106.4912	1.200165	MR_J_FT MJN_COP
2	0.08363359	-.05734586	4084.1443	1.139215	LMJN_OUT MJN_EXP
2	0.08412034	-.05678422	4081.9749	1.133298	LMJN_OUT MJN_COP
2	0.08465013	-.05617293	4079.6137	1.126858	LMJN_OT2 MJN_EXP
2	0.08472391	-.05608780	4079.2849	1.125961	LMJN_OT2 MJN_COP
2	0.09867377	-.03999180	4017.1118	0.956389	MJN_COP MJN_EXP
2	0.10366083	-.03423751	3994.8851	0.895767	MJN_COP DAY_REVS
2	0.11678410	-.01909527	3936.3961	0.736242	MJN_EXP DAY_REVS
2	0.19818343	0.07482704	3573.6082	-0.253236	MJN_COP MJN_WT
2	0.23032862	0.11191764	3430.3407	-0.643988	MJN_WT MJN_EXP
2	0.24841852	0.13279060	3349.7160	-0.863886	MJN_WT DAY_REVS
2	0.26355320	0.15025369	3282.2624	-1.0479	MR_J_FT MJN_WT
2	0.27339677	0.16161165	3238.3907	-1.1675	LMJN_OT2 MJN_WT
2	0.27615854	0.16479831	3226.0818	-1.2011	LMJN_OUT MJN_WT
3	0.01376476	-.23279405	4395.5420	3.988530	LMJN_OUT LMJN_OT2 DAY_REVS
3	0.01620227	-.22974717	4384.6783	3.958900	LMJN_OT2 MR_J_FT DAY_REVS
3	0.01624333	-.22969583	4384.4953	3.958401	LMJN_OUT LMJN_OT2 MR_J_FT
3	0.01635587	-.22955517	4383.9937	3.957033	LMJN_OUT MR_J_FT DAY_REVS
3	0.09103191	-.13621011	4051.1708	3.049282	LMJN_OUT LMJN_OT2 MJN_COP
3	0.09227006	-.13466242	4045.6525	3.034231	LMJN_OUT MR_J_FT MJN_COP
3	0.09440191	-.13199761	4036.1511	3.008317	LMJN_OT2 MR_J_FT MJN_COP
3	0.09830425	-.12711969	4018.7588	2.960881	LMJN_OUT LMJN_OT2 MJN_EXP
3	0.09945417	-.12568229	4013.6337	2.946902	MR_J_FT MJN_COP MJN_EXP
3	0.10405786	-.11992768	3993.1156	2.890941	LMJN_OUT MR_J_FT MJN_EXP
3	0.10407978	-.11990027	3993.0179	2.890674	LMJN_OUT MJN_COP MJN_EXP
3	0.10506134	-.11867333	3988.6432	2.878743	LMJN_OT2 MJN_COP MJN_EXP
3	0.10912856	-.11358930	3970.5160	2.829302	LMJN_OT2 MR_J_FT MJN_EXP
3	0.11010825	-.11236468	3966.1496	2.817393	LMJN_OT2 MJN_COP DAY_REVS
3	0.11104587	-.11119266	3961.9708	2.805995	LMJN_OUT MJN_COP DAY_REVS
3	0.11671103	-.10411121	3936.7218	2.737131	MR_J_FT MJN_COP DAY_REVS
3	0.13234922	-.08456348	3867.0241	2.547035	LMJN_OT2 MJN_EXP DAY_REVS
3	0.13521623	-.08097971	3854.2461	2.512184	LMJN_OUT MJN_EXP DAY_REVS
3	0.14131462	-.07335673	3827.0663	2.438053	MJN_COP MJN_EXP DAY_REVS
3	0.16007633	-.04990458	3743.4474	2.209988	MR_J_FT MJN_EXP DAY_REVS
3	0.23074451	0.03843063	3428.4871	1.350956	MJN_COP MJN_WT MJN_EXP
3	0.26162025	0.07702532	3290.8773	0.975635	MJN_COP MJN_WT DAY_REVS
3	0.26528200	0.08160251	3274.5573	0.931124	MR_J_FT MJN_COP MJN_WT
3	0.27343085	0.09178857	3238.2388	0.832068	LMJN_OT2 MJN_COP MJN_WT
3	0.27545584	0.09431980	3229.2136	0.807452	MR_J_FT MJN_WT MJN_EXP
3	0.27589325	0.09486656	3227.2641	0.802135	LMJN_OT2 MJN_WT DAY_REVS
3	0.27642018	0.09552522	3224.9157	0.795730	LMJN_OUT MJN_COP MJN_WT
3	0.27849796	0.09812244	3215.6552	0.770473	LMJN_OUT MJN_WT DAY_REVS
3	0.28085861	0.10107326	3205.1341	0.741777	LMJN_OT2 MR_J_FT MJN_WT
3	0.28206293	0.10257866	3199.7666	0.727137	MR_J_FT MJN_WT DAY_REVS
3	0.28209759	0.10262199	3199.6121	0.726716	LMJN_OUT LMJN_OT2 MJN_WT
3	0.28338380	0.10422975	3193.8796	0.711081	LMJN_OUT MR_J_FT MJN_WT
3	0.30087076	0.12608844	3115.9421	0.498512	LMJN_OT2 MJN_WT MJN_EXP
3	0.30091448	0.12614311	3115.7472	0.497981	LMJN_OUT MJN_WT MJN_EXP
3	0.33438849	0.16798562	2966.5573	0.0910754	MJN_WT MJN_EXP DAY_REVS

Appendix F. Regression search of potential effects of March to June environmental variables on the fall midwater trawl abundance index for delta smelt. See appendix H for Key to variable names.

N=14 REGRESSION MODELS FOR DEPENDENT VARIABLE: MWT_IND MODEL: MODEL1

NUMBER IN MODEL	R-SQUARE	ADJUSTED R-SQUARE	SSE	C(P)	VARIABLES IN MODEL
1	0.00014336	-.08317803	2920645.8	25.430383	LMJN_OT2
1	0.00085631	-.08240566	2918562.5	25.405119	LMJN_OUT
1	0.00249623	-.08062909	2913772.2	25.347008	DAY_REVS
1	0.00398817	-.07901282	2909414.1	25.294140	MJN_EXP
1	0.01024312	-.07223662	2891143.8	25.072493	MR_J_FT
1	0.15752201	0.08731551	2460932.8	19.853598	MJN_COP
1	0.30782448	0.25014319	2021888.9	14.527560	MJN_WT
2	0.00261506	-.17872766	2913425.1	27.342797	LMJN_OUT DAY_REVS
2	0.00388605	-.17722558	2909712.4	27.297759	LMJN_OT2 DAY_REVS
2	0.00414336	-.17692148	2908960.8	27.288641	LMJN_OT2 MJN_EXP
2	0.00471141	-.17625015	2907301.5	27.268512	MJN_EXP DAY_REVS
2	0.00497157	-.17594269	2906541.5	27.259293	LMJN_OUT MJN_EXP
2	0.01024325	-.16971253	2891142.6	27.072489	MR_J_FT DAY_REVS
2	0.01533291	-.16369747	2876275.4	26.892134	LMJN_OUT MR_J_FT
2	0.01740101	-.16125335	2870234.3	26.818858	MR_J_FT MJN_EXP
2	0.02046772	-.15762906	2861276.3	26.710180	LMJN_OT2 MR_J_FT
2	0.11181617	-.04967180	2594441.6	23.473205	LMJN_OUT LMJN_OT2
2	0.15782147	0.00469810	2460057.2	21.842986	MJN_COP DAY_REVS
2	0.16523995	0.01346540	2438387.4	21.580109	LMJN_OT2 MJN_COP
2	0.17041767	0.01958451	2423262.9	21.396634	LMJN_OUT MJN_COP
2	0.20420359	0.05951333	2324572.1	20.199414	MR_J_FT MJN_COP
2	0.21899222	0.07699080	2281373.6	19.675372	MJN_COP MJN_EXP
2	0.31695692	0.19276727	1995212.4	16.203948	MJN_WT MJN_EXP
2	0.32616822	0.20365336	1968305.6	15.877541	MJN_WT DAY_REVS
2	0.32638517	0.20390974	1967671.9	15.869853	MR_J_FT MJN_WT
2	0.33487614	0.21394453	1942869.2	15.568972	MJN_COP MJN_WT
2	0.33694797	0.21639306	1936817.3	15.495555	LMJN_OUT MJN_WT
2	0.34287576	0.22339862	1919501.8	15.285502	LMJN_OT2 MJN_WT
3	0.00496994	-.29353907	2906546.3	29.259351	LMJN_OT2 MJN_EXP DAY_REVS
3	0.00497666	-.29353034	2906526.7	29.259113	LMJN_OUT MJN_EXP DAY_REVS
3	0.01863274	-.27577743	2866636.4	28.775203	LMJN_OUT MR_J_FT DAY_REVS
3	0.02118697	-.27245694	2859175.3	28.684693	MR_J_FT MJN_EXP DAY_REVS
3	0.02510041	-.26736946	2847743.9	28.546018	LMJN_OUT MR_J_FT MJN_EXP
3	0.02767892	-.26401740	2840211.9	28.454648	LMJN_OT2 MR_J_FT DAY_REVS
3	0.03257719	-.25764965	2825903.8	28.281075	LMJN_OT2 MR_J_FT MJN_EXP
3	0.12622952	-.13590162	2552339.3	24.962461	LMJN_OUT LMJN_OT2 DAY_REVS
3	0.17316716	-.07488269	2415231.5	23.299204	LMJN_OUT LMJN_OT2 MR_J_FT
3	0.17906853	-.06721092	2397993.2	23.090087	LMJN_OUT LMJN_OT2 MJN_EXP
3	0.18625393	-.05786989	2377004.2	22.835469	LMJN_OT2 MJN_COP DAY_REVS
3	0.20229296	-.03701916	2330153.2	22.267118	LMJN_OUT MJN_COP DAY_REVS
3	0.20895398	-.02835982	2310695.9	22.031082	LMJN_OUT MR_J_FT MJN_COP
3	0.21723206	-.01759832	2286515.1	21.737744	LMJN_OT2 MR_J_FT MJN_COP
3	0.22625222	-.00587211	2260166.6	21.418111	MJN_COP MJN_EXP DAY_REVS
3	0.23358763	0.00366392	2238739.4	21.158177	MR_J_FT MJN_COP DAY_REVS
3	0.23487803	0.00534144	2234970.1	21.112451	LMJN_OT2 MJN_COP MJN_EXP
3	0.24073285	0.01295271	2217867.8	20.904983	LMJN_OUT MJN_COP MJN_EXP
3	0.26236440	0.04107372	2154680.7	20.138459	MR_J_FT MJN_COP MJN_EXP
3	0.32890932	0.12758212	1960298.7	17.780409	MJN_WT MJN_EXP DAY_REVS
3	0.33375731	0.13388450	1946137.4	17.608618	MR_J_FT MJN_WT DAY_REVS
3	0.33736038	0.13856849	1935612.6	17.480942	LMJN_OUT MR_J_FT MJN_WT
3	0.33743693	0.13866801	1935389.0	17.478229	LMJN_OUT MJN_WT DAY_REVS
3	0.33779659	0.13913557	1934338.4	17.465484	MR_J_FT MJN_COP MJN_WT
3	0.34287576	0.14573849	1919501.8	17.285502	LMJN_OT2 MR_J_FT MJN_WT
3	0.34288982	0.14575676	1919460.8	17.285004	LMJN_OT2 MJN_WT DAY_REVS
3	0.34714188	0.15128444	1907040.2	17.134330	LMJN_OUT MJN_COP MJN_WT
3	0.34993780	0.15491913	1898873.2	17.035255	MR_J_FT MJN_WT MJN_EXP
3	0.35160616	0.15708801	1893999.8	16.976136	LMJN_OUT MJN_WT MJN_EXP
3	0.35227786	0.15796122	1892037.7	16.952334	LMJN_OT2 MJN_COP MJN_WT
3	0.35452653	0.16088449	1885469.2	16.872651	MJN_COP MJN_WT DAY_REVS
3	0.35668859	0.16369517	1879153.7	16.796037	LMJN_OT2 MJN_WT MJN_EXP
3	0.39365378	0.21174981	1771176.2	15.486162	MJN_COP MJN_WT MJN_EXP
3	0.43054898	0.25971367	1663402.8	14.178760	LMJN_OUT LMJN_OT2 MJN_WT
3	0.44276665	0.27559664	1627714.2	13.745822	LMJN_OUT LMJN_OT2 MJN_COP

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Appendix G. Regression search of potential effects of July to October environmental variables on the fall midwater trawl abundance index for delta smelt. See appendix H for Key to variable names.

N=14 REGRESSION MODELS FOR DEPENDENT VARIABLE: MWT_IND MODEL: MODEL1

NUMBER IN MODEL	R-SQUARE	ADJUSTED R-SQUARE	SSE	C(P)	VARIABLES IN MODEL
1	0.00130751	-.08191686	2917244.5	28.059097	LJ_O_OT2
1	0.00303352	-.08004702	2912202.7	27.993321	J_O_EXP
1	0.00353265	-.07950629	2910744.7	27.974300	LJ_O_OUT
1	0.00571686	-.07714007	2904364.5	27.891062	JL_OFT
1	0.03338527	-.04716596	2823543.3	26.836649	DAY_REVF
1	0.25866386	0.19688585	2165490.2	18.251524	JL_O_COP
1	0.36666982	0.31389231	1849997.9	14.135532	JO_WT
2	0.00416421	-.17689684	2908699.9	29.950232	LJ_O_OT2 J_O_EXP
2	0.00612686	-.17457734	2903166.8	29.875437	J_O_EXP JL_OFT
2	0.00641868	-.17423247	2902314.4	29.864316	LJ_O_OUT J_O_EXP
2	0.01694467	-.16179267	2871567.4	29.463182	LJ_O_OT2 JL_OFT
2	0.02384620	-.15363630	2851407.5	29.200172	LJ_O_OUT JL_OFT
2	0.03911606	-.13559011	2806803.3	28.618254	J_O_EXP DAY_REVF
2	0.04152319	-.13274532	2799771.9	28.526521	LJ_O_OUT DAY_REVF
2	0.04255564	-.13152516	2796756.1	28.487176	JL_OFT DAY_REVF
2	0.04948508	-.12333582	2776514.7	28.223102	LJ_O_OT2 DAY_REVF
2	0.26318064	0.12921348	2152296.4	20.079394	JL_O_COP JL_OFT
2	0.26445781	0.13072287	2148565.7	20.030722	JL_O_COP J_O_EXP
2	0.26531810	0.13173957	2146052.7	19.997938	LJ_O_OT2 JL_O_COP
2	0.26691795	0.13363030	2141379.4	19.936969	LJ_O_OUT LJ_O_OT2
2	0.26859214	0.13560889	2136489.0	19.873167	LJ_O_OUT JL_O_COP
2	0.31324298	0.18837807	2006061.1	18.171572	JL_O_COP DAY_REVF
2	0.36701013	0.25192106	1849003.8	16.122564	JO_WT DAY_REVF
2	0.36713721	0.25207125	1848632.6	16.117721	JO_WT J_O_EXP
2	0.37098812	0.25662232	1837383.8	15.970967	LJ_O_OUT JO_WT
2	0.37199556	0.25781294	1834441.0	15.932574	LJ_O_OT2 JO_WT
2	0.37826357	0.26522058	1816131.8	15.693707	JO_WT JL_OFT
2	0.69578315	0.64047099	888636.8	3.593377	JL_O_COP JO_WT
3	0.01861599	-.27579921	2866685.3	31.399490	LJ_O_OT2 J_O_EXP JL_OFT
3	0.02641678	-.26565819	2843898.7	31.102210	LJ_O_OUT J_O_EXP JL_OFT
3	0.04333182	-.24366863	2794488.8	30.457596	LJ_O_OUT JL_OFT DAY_REVF
3	0.04948922	-.23566401	2776502.6	30.222944	LJ_O_OT2 JL_OFT DAY_REVF
3	0.08124338	-.19438361	2683746.7	29.012827	LJ_O_OUT J_O_EXP DAY_REVF
3	0.08699869	-.18690170	2666935.1	28.793499	J_O_EXP JL_OFT DAY_REVF
3	0.10105707	-.16862581	2625869.7	28.257749	LJ_O_OT2 J_O_EXP DAY_REVF
3	0.26560361	0.04528469	2145218.7	21.987057	JL_O_COP J_O_EXP JL_OFT
3	0.27059762	0.05177691	2130630.9	21.796741	LJ_O_OT2 JL_O_COP J_O_EXP
3	0.27207674	0.05369976	2126310.3	21.740373	LJ_O_OUT LJ_O_OT2 JL_OFT
3	0.27409046	0.05631760	2120428.1	21.663632	LJ_O_OUT JL_O_COP J_O_EXP
3	0.28798367	0.07437877	2079845.1	21.134177	LJ_O_OT2 JL_O_COP JL_OFT
3	0.29533035	0.08392946	2058385.0	20.854203	LJ_O_OUT JL_O_COP JL_OFT
3	0.31995144	0.11593687	1986465.2	19.915920	LJ_O_OUT JL_O_COP DAY_REVF
3	0.32121710	0.11758223	1982768.2	19.867687	JL_O_COP J_O_EXP DAY_REVF
3	0.32180560	0.11834728	1981049.1	19.845260	JL_O_COP JL_OFT DAY_REVF
3	0.32573019	0.12344924	1969585.1	19.695698	LJ_O_OT2 JL_O_COP DAY_REVF
3	0.36717777	0.17733109	1848514.1	18.116175	JO_WT J_O_EXP DAY_REVF
3	0.37146369	0.18290279	1835994.7	17.952843	LJ_O_OUT JO_WT J_O_EXP
3	0.37216045	0.18380859	1833959.4	17.926290	LJ_O_OUT JO_WT DAY_REVF
3	0.37238843	0.18410495	1833293.5	17.917603	LJ_O_OT2 JO_WT J_O_EXP
3	0.37388822	0.18605468	1828912.5	17.860447	LJ_O_OT2 JO_WT DAY_REVF
3	0.37947638	0.19331930	1812589.1	17.647488	JO_WT J_O_EXP JL_OFT
3	0.38020262	0.19426341	1810467.7	17.619812	JO_WT JL_OFT DAY_REVF
3	0.40937631	0.23218921	1725249.5	16.508034	LJ_O_OUT LJ_O_OT2 JO_WT
3	0.40963462	0.23252501	1724494.9	16.498190	LJ_O_OUT LJ_O_OT2 J_O_EXP
3	0.42150144	0.24795187	1689831.2	16.045959	LJ_O_OUT JO_WT JL_OFT
3	0.42446933	0.25181013	1681161.8	15.932855	LJ_O_OT2 JO_WT JL_OFT
3	0.43376093	0.26388922	1654020.4	15.578762	LJ_O_OUT LJ_O_OT2 JL_O_COP
3	0.43547960	0.26612348	1649000.1	15.513266	LJ_O_OUT LJ_O_OT2 DAY_REVF
3	0.69580992	0.60455290	888558.6	5.592357	JL_O_COP JO_WT J_O_EXP
3	0.69621217	0.60507582	887383.6	5.577028	JL_O_COP JO_WT DAY_REVF
3	0.69679479	0.60583323	885681.6	5.554825	LJ_O_OT2 JL_O_COP JO_WT
3	0.69680044	0.60584057	885665.3	5.554609	LJ_O_OUT JL_O_COP JO_WT
3	0.71429518	0.62858374	834562.0	4.887903	JL_O_COP JO_WT JL_OFT

Appendix H. Key to the variables used in regression search of environmental variables affecting delta smelt abundance.

March-June Variables

LMJN_OUT=	Log_{10} Mean March-June Delta outflow.
LMJN_OT2=	Log_{10} Mean March-June Delta outflow squared.
DAY_REVS=	Number of March-June days of reverse flow.
MJN_EXP=	Mean March-June water project exports.
MR_J_FT=	Mean Maximum March-June Sacramento River Temperature at Freeport.
MJN_COP=	Mean March-June copepod density/m^3 exclusive of Sinocalanus and nauplii.
MJN_WT=	Mean March-June water transparency (secchi).

July-October Variables

LJ_O_OUT=	Log_{10} mean July-October Delta outflow.
LJ_O_OT2=	Log_{10} mean July-October Delta outflow squared.
DAY_REVF=	Number of July-October days of reverse flows.
J_O_EXP=	Mean July-October water project exports.
J_OFT=	Mean July-October maximum Sacramento River temperature at Freeport.
JL_O_COP=	Mean July-October copepod density/m^3 exclusive ofSinocalnus and nauplii.
JO_WT=	Mean July-October water transparency (secchi).